



**Heat Stress Evaluation of Special Operations Aviation
Regiment and Air Warrior Concept 1 and 3
Aviator Ensembles in a UH-60 Simulator**

By

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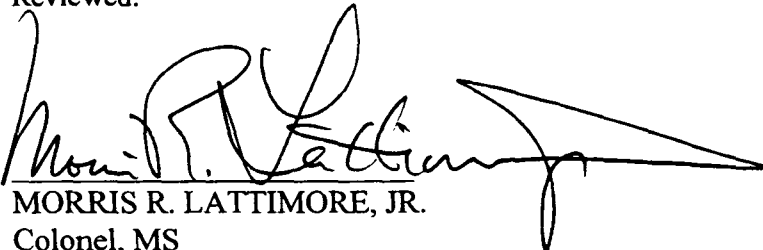
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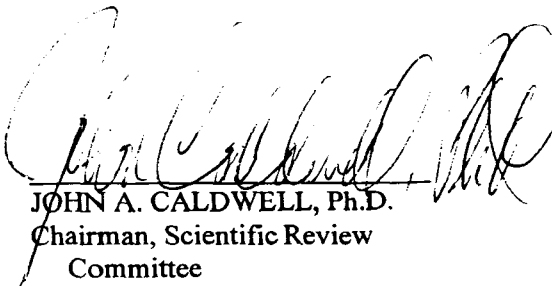
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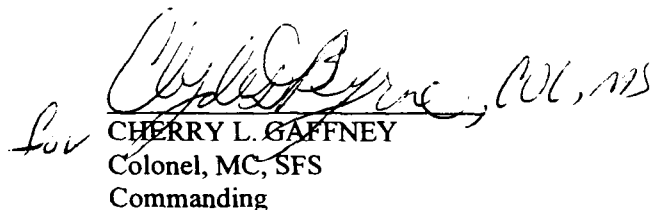


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Mean core (rectal thermistor) temperatures, in °F, just prior to exiting the simulator, were: SC=99.1, SX=101.0, AC=98.9, and AX=101.5. Similarly, end-session heart rates, in beats per minute, were: SC=69, SX=118, AC=62, and AX=130. The ensembles with MCC (SC and AC) resulted in 6.09°F lower chest and 6.29°F lower arm temperatures. Mean total sweat rates were: SC=199.3, SX=753, AC=203, and AX=764 ml per hour. Mood and symptom responses indicated greater comfort and less stress when MCC was used. There was a time-dependent progression of adverse heat stress symptoms when MCC was not used. Ratings that were higher with MCC were those for perceived energy and boredom. Flight performance was not evaluated since the crews were not UH-60 trained. The results of ranking 27 measurements indicated that ensemble AC had the best heat stress mitigation effects, followed, in order of decreasing heat stress performance, by SC, SX, and AX.

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Introduction

This study was implemented to compare physiological and psychological effects of heat stress exposure on aviators wearing current Special Operations Aviation Regiment (SOAR) and Air Warrior Concepts 1 and 3 encumbered chemical defense level-4 mission oriented protective posture (MOPP4) ensembles. The evaluation was performed at the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama, during June 1998 for the Commander, 160th SOAR, and the Air Warrior (AW) project manager operating under the program manager (PM), U.S. Army Aircrew Integrated Systems (ACIS). Funding was provided by the U.S. Army 160th SOAR unit and PM ACIS. The objective of the study was to provide data to the SOAR commander and AW/ACIS PM regarding the differences in mission endurance, physiological strain, and psychological heat stress responses between the different MOPP4 aviator uniforms with and without microclimate cooling.

SOAR units frequently deploy on classified missions to remote, austere environments. Crews may be exposed to hot weather, and missions typically emphasize extensive nap-of-the-earth maneuvering. Since distances to objectives may exceed aircraft fuel capacity, inflight refueling is often part of extended duration flight profiles. SOAR commanders and aircrew are aware that heat stress can limit crew and mission endurance and add to the general stress and discomfort of lengthy flights predisposing to decreased performance and accident risk margins. These factors motivated their effort to evaluate the effectiveness and practicality of liquid microclimate cooling garment systems for reducing heat strain and risks of heat stress-induced mission delays or aborts.

The AW project is a joint Army, Navy, and USMC long-range research and development effort to incrementally develop state-of-the-art rotary-wing combat-capable aircrew ensembles using integrated soldier-system design methods. The primary AW goal is to globally enhance aviator effectiveness and survivability when conducting military operations across conditions spanning a complex spectrum of mission and environment-related performance and survivability risks. New-generation aviator ensemble prototypes are being developed by industry to meet AW design goals of modularity, mission configurability, protection against chemical agents, integrated advanced life support, and ballistic protection (ATCOM, 1995).

Background

Environmental and mission-related heat stress factors

Aviators can be exposed to substantial heat stress when performing outdoor preflight duties and flying unair-conditioned transport helicopters in hot weather environments. The environmental components of heat stress include elevated ambient temperature, humidity, wind speed, and radiant heat load. These heat stress components are frequently expressed as a composite indicator, or index, such as the wet-bulb globe temperature (WBGT) used by the U.S. military.

Mission factors that aggravate the effects of environmental heat stress include requirements to wear occlusive aviator MOPP ensembles. These ensembles are typically encumbered with additional ballistic protection and survival gear that further retard heat dissipation and sweat evaporation. Mission-oriented sustained operational tempo can cause increased activity levels with persistently elevated metabolic rates and lead to fatigue. Increases in metabolic rates contribute to heat stress, and fatigue impairs preventative behavior such as continuous rehydration. Aircraft configurations (e.g., doors and windows closed) may also enhance thermal stress in crew compartments via greenhouse effects.

Individual aircrew factors such as illness, fever, medications (particularly those with anticholinergic properties), and dehydration can also significantly reduce thermoregulatory capabilities and lower the threshold and rate of progression of heat strain and heat illness. Such effects increase the likelihood of performance decrements, failure to complete missions, and occurrence of heat illness.

Numerous field studies have documented dramatic increases in helicopter cockpit temperatures during sunny hot weather. Breckenridge and Levell (1970), for example, measured WBGT readings within the closed cockpit of a parked AH-1G attack helicopter fully exposed to summertime solar radiation at an airfield near Savannah, Georgia. They found that cockpit WBGT typically was greater than 104°F and dry-bulb air temperatures up to 132 °F. Froom et al. (1991) demonstrated that, 1 hour after moving into full sunlight, cockpit WBGT in a Bell 212 helicopter was 13°F (7.2°C) greater than ambient WBGT. Likewise, Thornton and Guardiani (1992) showed that summertime WBGT in the closed cockpit of a hovering UH-60 transport helicopter was approximately 9°F (5°C) higher than at nearby airfields.

High cockpit and cabin temperatures occur because of heat transfer into crew compartments from hot external environments, as well as heat sources from aircraft systems, such as engines, auxiliary power units, and electronic modules. The greenhouse effect exacerbates stress by trapping heat in relatively small, poorly ventilated, crew compartments.

Greenhouse effects occur in enclosures having windows that transmit visible-band solar energy, but are relatively opaque to the longer wavelength infrared (IR) radiation emitted from interior surfaces and crewmembers. Additionally, elevated humidity and carbon dioxide levels in closed crew compartments facilitate cabin air absorption of radiated and transmitted IR energy. The elevated dry bulb temperatures due to IR energy trapped by the air in an aircraft cabin along with the primary heat stress effects of increased humidity from respiration and evaporating sweat contribute to increased cockpit WBGT heat stress index.

Physiological heat stress responses and chemical defense (CD) ensembles

Physiologically, when endogenous or exogenous factors cause net heat storage within body tissue compartments, protective compensatory heat dissipating processes are progressively activated to prevent an increase in core temperature (Epstein, Strochein, and Pandolf, 1987).

Primary thermoregulatory processes include sweating, peripheral vasodilatation, increased cardiac output, and shunting of blood flow from central visceral organs to the skin. Other heat stress responses are only discernable at cellular and biochemical levels.

The metabolic rate for routine flight maneuvers in military helicopters is in the range of 100-200 watts, falling into the category of light physical work (e.g., Thornton, Brown, and Higgenbottom, 1984). Therefore, the contribution of metabolic thermogenesis to rise in core temperature during routine flight is usually relatively minor. However, if cockpit conditions are sufficiently hot, even slight metabolic heat gain can cause aviator core temperature to relentlessly increase to levels that cause discomfort, impair performance, and eventually cause heat illness.

Mission oriented protective posture (MOPP) is a term used with a numerical suffix (0-4) to signify five standard levels of personal protection against chemical and biological (CB) threats. Unit commanders designate appropriate MOPP levels for their units based on intelligence estimates of the nature and immediacy of CB threats. Although MOPP ensembles vary somewhat across the services, typical MOPP components include a chemical agent absorbent over- or undergarment, CB protective mask and impermeable hood, and butyl rubber protective gloves and boots. These components are worn simultaneously to provide level four MOPP (MOPP4) CB protection. Although there has been a continuous improvement in the design and biophysical properties of MOPP4 components, complete MOPP4 ensembles still remain bulky, insulating, impermeable, and encumbering. All these factors can significantly impair thermoregulation as well as performance (e.g., Lussier and Fallesen, 1987; Gonzalez, 1988; Taylor and Orlansky, 1993; Muza, Bandaret, and Forte, 1995; and Ramsey, 1995).

Low water vapor permeability for CD ensembles signifies reduced maximum rates of evaporative skin cooling. When ambient temperatures exceed body temperature, sweat evaporation is the only effective method of dissipating body heat (Sawka and Wenger, 1988). Complete evaporation of 1 liter of sweat provides 580 kcal of surface cooling. However, effective sweat rates, as determined by the rate of evaporation of sweat from a uniform, determines the evaporative cooling power available to the individual. It is apparent, therefore, that actual and effective sweating rates may differ considerably.

In heat stress conditions, low water vapor permeability causes the air layer between the skin and inner surface of a CD ensemble to rapidly saturate with sweat vapor. As this occurs, the net evaporation of sweat decreases and approaches zero. The unevaporated sweat is then either absorbed into the flight uniform and overgarments and accumulates in dependent parts such as boots, gloves, and mask. Since the unevaporated sweat cannot be used for cooling, it only contributes, in a deleterious manner, to dehydration.

Methods and procedures

Study design

The original scheme was to conduct this study using a repeated measures design. However, test subject availability and funding limitations resulted in a mixed (between and within test subjects) and incomplete factorial implementation. There was one environmental condition, and, as indicated in figure 1, a MOPP4 ensemble factor with three levels (SOAR, AW Concept 1, and AW Concept 3), and a microclimate cooling (MCC) factor with two levels (with and without). The order of testing is depicted in figure 2. Data were obtained to characterize the physiologic and subjective heat stress responses for the different factor levels.

| | SOAR | AW Concept 1 | AW Concept 3 |
|-------------|------|--------------|--------------|
| With MCC | + | * | + |
| Without MCC | + | + | * |

| | SOAR | AW |
|-------------|------|----|
| With MCC | + | + |
| Without MCC | + | + |

+: tested *: not tested

Figure 1. Collapsing the 2 AW Concept ensembles into a composite AW level because of incomplete factorial implementation.

| | Tues, 6/16 | Wed, 6/17 | Thurs, 6/18 | Fri, 6/19 | Sat, 6/20 | Sun, 6/21 |
|------|------------|-----------|-------------|-----------|-----------|-----------|
| Crew | 2 | 1 | 2 | 1 | 2 | 1 |
| TS 1 | | SC | | AC | | SX |
| TS 2 | | SC | | AX | | SX |
| TS 3 | SX | | SC | | AC | |
| TS 4 | SX | | SC | | AX | |

Legend:

| | |
|----|---------------------------------|
| TS | Test Subject |
| SC | SOAR-specific MOPP4 with MCC |
| SX | SOAR-specific MOPP4 without MCC |
| AC | AW MOPP4 Concept3 with MCC |
| AX | AW MOPP4 Concept1 without MCC |

Figure 2. Order of testing by crew, test subject, and ensemble.

Four volunteer aviators were tested as two 2-man crews. Each crew participated in three heat stress exposure sessions during one week of testing. The limited number of available test subjects did not permit full counterbalancing with respect to order of factor levels. The two crews were tested in SOAR-specific MOPP4 without MCC and in SOAR MOPP4 with MCC. There were also two sessions wherein one crewmember wore the Air Warrior Concept 1 MOPP4 ensemble without MCC and the other crewmember wore Air Warrior Concept 3 MOPP4 ensemble with MCC.

Sequence of test session events

Prior to study participation, the volunteer crews received a detailed briefing regarding the study and were informed of their right to withdraw at any time, at their discretion, without penalties. The volunteers read and signed the approved informed consent and then were medically screened for evidence of disqualifying conditions (e.g., significant medical conditions, history of heat stroke or recurrent heat illness of lesser severity, and use of prescription medication) or indicators of excess cardiovascular, musculoskeletal, or other health risks.

Test subjects arrived at USAARL each day during the test week at approximately 0700, self-inserted a rectal thermistor, had skin temperature sensors and electrocardiogram (ECG) leads applied, and then donned the designated MOPP4 aviator ensemble (Appendix A). They subsequently entered an environmental chamber for a 20-minute treadmill walk at a 3 mph pace and 0 percent grade. This was done (per Thornton et al., 1992 and Reardon, et al., 1996 and 1997) to approximate the metabolic heat generated during an actual UH-60 preflight inspection.

According to the 160th SOAR pilots, they do not usually perform preflight inspections in MOPP4. In such circumstances, preflight checks on their aircraft are done by off-duty pilots or others specifically assigned to do so. However, in most other Army aviation units, flight crews are responsible for preflighting their own aircraft regardless of the required MOPP level. Therefore, the simulated preflight treadmill walk was retained in the study design for generalizability of results, as well as to maintain data comparability with the previous heat stress studies that used this method.

After completing the 20-minute simulated preflight inspection on the treadmill, crews walked a short distance in their ensemble to the USAARL UH-60 simulator. Throughout each test session, core temperature and heart rate were monitored every 10 minutes to verify adherence to physiological limits as approved in the research protocol (core temperature limit of 102.56 °F, or 39.2 °C, and heart rate not to exceed 90 percent of age-adjusted predicted maximum). Pre- and post-test weights and fluid intake and output were obtained to determine mean sweat rates and dehydration levels.

Each UH-60 simulator session consisted of three consecutive 2-hour sorties (air assault (AA), medical evacuation (MEDEVAC), and repeat of the AA. Since flight performance was not evaluated, crewmembers were allowed to self-regulate their time on the controls. A 10-minute simulated hot refueling break was allowed between sorties. This time was used for equipment adjustment, water resupply, and use of the bathroom as needed. Except for the latter, the crew stayed in the heated simulator during those 10-minute segments. During the sorties, the study technician in the simulator and data acquisition systems collected physiological data. When subjective or objective evidence suggested that physical or subjective tolerance limits were about to be reached, the crew was instructed to make a simulated landing. The affected crewmember(s) was then expeditiously assisted out of the simulator for supervised cooling and recovery.

Environmental conditions

The pilots in this study were tested only in the hot condition as defined in Reardon et al. (1997). This consisted of 100 °F (dry-bulb) and 20 percent relative humidity (RH) in the environmental chamber for the 20 minute simulated outdoor preflight, and 100 °F and 50 percent RH (resulting in a WBGT of 90 °F) in the UH-60 simulator. The WBGT value in the simulator included the radiant black-globe effects from three sets of heat lamps situated above each pilot's helmet. Lamp rheostats were set at 50 percent per Thornton et al. (1992).

Aviator ensembles

Annotated photographs of the U.S. Army SOAR and AW Concepts 1 and 3 rotary-wing ensembles, as well as average component and total weights as tested in this study, are provided in Appendix B. The complete SOAR-specific ensembles with and without the MCC undershirt weighed 38.84 and 40.52 pounds, respectively. The AW Concept 1 ensemble, which did not include MCC, weighed 49.15 pounds. Likewise, the total weight for the AW Concept 3 aviator ensemble with MCC undershirt was 51.97 pounds.

Microclimate cooling system

The microclimate (personal) cooling device used in this study (see Appendix C for detailed description) was the Portable Vapor-Compression Cooling System (PVCS). The PVCS consisted of a relatively compact upper refrigeration/pump unit weighing about 10 pounds and a lower lithium sulfur-dioxide battery module having a weight of about 11 pounds. The refrigeration/pump circulated water cooled with a vapor compression refrigerant. Water lines from the cooling unit to the plastic tubing in the cooling shirt were insulated with rubber foam collars, except close to the refrigeration/pump unit and garment connection, where the lines were exposed to ambient conditions.

Specified operational duration with the battery module was approximately 4 hours. The refrigeration/pump module had a 24-volt connector for use in the simulator; obviating the need for the battery module during that portion of the test sessions. The listed heat extraction rate for the MCC in battery mode was 300 watts.

Although a complete PVCS ensemble includes shirt, pant, and hood heat transfer garments, the crews in this study used only the cooling undershirt (see Appendix C). The pilots wore the cooling undershirt over a standard cotton military T-shirt for comfort.

USAARL's UH-60 research helicopter simulator

Capabilities and data acquisition

The current USAARL UH-60 research simulator has a hydraulic motion base that provides 6 degrees freedom of motion. This allows generation of acceleration cues in lateral, longitudinal, and vertical directions with pitch, roll, and yaw over a 60-degree range. The simulator has a three-channel, four-window, digital image generator (DIG).

The UH-60 research simulator was equipped with an environmental control unit (ECU) that maintained target dry-bulb temperature and RH in the cockpit during the study. The ECU was capable of controlling cockpit conditions within a range of 68-105 °F (± 3 °F) and 50-90 percent RH (± 3 percent).

A physiological data acquisition system in the simulator captured physiological data from crewmembers (USAARL, 1991). This also allowed continuous monitoring of core temperature and heart rate to ensure compliance with approved protocol limits for physiological parameters.

As an additional safety measure, the volunteer aviators were also remotely observed by video cameras during simulator sessions. Two cameras were positioned to monitor the pilots' faces for signs of excessive heat strain and a forward-looking camera fixed to the top of the instrument glare-shield allowed remote monitoring of the view out the left front window. The volunteers were informed about the camera system and provided written recording and photography consent.

Automatic flight control system

Like the actual UH-60 Blackhawk medium transport helicopter, the USAARL UH-60 simulator is equipped with an automatic flight control system (AFCS) which enhances stability and handling qualities (Department of the Army, 1994). The AFCS has four subsystems: The stabilator, the stability augmentation system (SAS), the trim system, and flight path stabilization (FPS). The stabilator, a 14 foot variable angle-of-incidence airfoil, provides control in the pitch axis and a level attitude at a hover. The SAS enhances dynamic stability in all axes, thus preventing "porpoising" in the pitch axis, rolling in the roll axis, and "fishtailing" in the yaw axis. The trim system consists of three trims for pitch, roll, and yaw axes. The trim function provides cyclic (pitch and roll) and pedal (yaw) flight control position reference and control gradient to maintain the cyclic stick and pedals at a desired position.

FPS is also provided for the pitch, roll and yaw axes. FPS provides very low frequency dampening (static stability). FPS functions maintain helicopter pitch attitude/airspeed hold, roll attitude hold, and heading hold and automatic turn coordination.

Flight profiles (sorties)

During test sessions, crews attempted to complete three sequential realistic 2-hour sorties in the heated UH-60 simulator (consistent with USAAC, 1989). These sorties were identical to those described by Reardon et al. (1997 and 1998). The entire simulator mission, or scenario, for each test session consisted of consecutive AA, MEDEVAC, and repeat AA sorties with intervening 10-minute (simulated) hot-refuel breaks which also sufficed for use of latrines and canteen refills.

Every 30 minutes during each test session, the right seat pilot flew a 10-minute set of standard flight maneuvers. Prior to each set of standard maneuvers, the simulator operator initiated simulated IMC conditions. The pilot then ascended to 2,000 feet to start the maneuver set. After the last standard maneuver in each set, the pilot descended out of IMC to resume visual flight rules (VFR) contour and nap-of-the-earth (NOE) flight along the designated path. The sets of standard flight maneuvers were designed to be well integrated into the underlying scenario. The set of standard flight maneuvers was flown 4 times during each 2-hour flight mission or 12 times for the complete 6-hour simulator session. Since flight performance was not evaluated in this study, the set of standard maneuvers were flown merely to keep pilot activity and attention levels consistent with previous similar heat stress evaluations.

Flight performance measurement

Unfortunately, flight performance was not evaluated during this study because the volunteers, although very experienced aviators, were not UH-60 qualified and were not available for sufficient time to train to asymptotic flight performance levels in the UH-60 simulator.

Physiological measurement methods

Heart rate

Heart rate was recorded with a three-lead system using Ver-Med electrodes*. Since the leads were connected to a battery powered R-wave counter, the electrodes were positioned to maximize R-wave tracings. When necessary, a small amount of hair over electrode locations was shaved to obtain sufficient skin-to-electrode contact to reduce the risk of losing heart rate capture from sweating and movement.

Core temperature

Core temperature was measured with a self-inserted YSI 401* rectal thermistor. Prior to use, temperature sensors were calibrated in a stirred water bath with a precision calibrating thermometer.

* See appendix H, Manufacturers and product information

The rectal thermistor has proven to be quite safe when used by test subjects who are healthy and do not have inflammatory bowel or rectosigmoid diseases or strictures. Prospective volunteers were medically screened to detect criteria precluding use of such thermistors. None of the volunteers had exclusionary conditions and none incurred adverse effects from their use.

Skin temperature

Skin temperature was measured with four YSI 400 series* surface thermistors held in position with collodion and strips of cloth tape. The skin temperature thermistors were placed on the anterior chest, upper lateral arm, lateral thigh, and lateral calf.

Collodion affixed the sensors securely to the skin to prevent sweat-associated separation. The skin was inspected daily to avoid placing these sensors on any lesions and to detect early evidence of irritation or metallic sensitization reactions. After each use, sensors were cleaned and allowed to air dry.

Dehydration

Pre- and post-study session, total undressed and dressed weights were obtained in order to determine the amount of cumulative dehydration and sweating that occurred during each test session.

Prior to starting each test session, the volunteer aviators first urinated and then obtained a nude weight. They self-inserted their individual rectal thermistor. A technician then applied the skin temperature and ECG sensors. Next, test subjects donned the appropriate encumbered MOPP4 ensemble, and a dressed weight was obtained. Before and after each test session, fluids and snack foods were individually weighed. Voided urine was also collected and weights recorded. At the end of each day's test session, a fully clothed weight was again obtained. The ensemble was then removed and a post-session nude weight obtained. Body weight and fluid data were recorded on a form (appendix D) which facilitated subsequent analysis.

Dehydration was calculated by using the term: $100 * [(weight_{sweat\ loss} + weight_{urine\ output} - weight_{water}) / weight_{initial\ nude}]$. Sweat loss estimate was obtained from the term: $(weight_{initial\ nude} - weight_{post\ nude}) + (weight_{water} + weight_{food} - weight_{urine})$. Total sweat loss minus evaporated sweat permitted assessment of the amount of sweat retained in the ensemble. For each test session, total amounts of sweat, sweat rates, amount of sweat evaporated, and amount retained in the uniform were able to be determined.

Psychological evaluation methods

Mood and symptoms

A 12-question mood and symptoms questionnaire was administered before and approximately every 2 hours after the volunteer pilots began the treadmill session in the environmental chamber

(appendix C). Using a 0-10 Likert scale (0=none, 10=maximum), the volunteers assessed their sensation of: headache, nausea, stress, anger, depression, energy, heat stress, thirst, workload, boredom, dizziness, and visual difficulty. Hot spot (pressure point discomfort) locations and intensities were also reported.

Data analysis

The small number of test subjects in this study, as well as the mixed between/within test subject implementation, precluded use of standard parametric statistical analysis. Therefore, comparison of SOAR and AW Concept heat stress results are primarily presented graphically. In subsequent charts and graphs, the 95 percent confidence interval (CI) (mean \pm 2 standard errors) for the selected MOPP4 aviator ensemble defines the range within which the mean for other ensemble results must fall to justify a conclusion of no statistically significant difference between responses (see Dawson-Saunders and Trap, 1994, Chapter 7).

Results

Test subjects

Four U.S. Army male warrant officer rotary-wing aviators voluntarily participated in this study. All completed the study without injury or complications. Mean age was 39.5 years (range: 30-48) with mean weight and height 197 pounds and 72 inches, respectively (Appendix D). They reported an average of 5.6 hours of physical fitness training per week and performed an average of 81 sit-ups and 74 pushups and had a 2 mile run time of 13:54 for their most recent Army physical fitness test. This indicated that the test subjects were in excellent physical condition. The aviators had received an average of 3.25 hours of heat illness prevention training over the past 2 years. Only two of the pilots had worn MOPP4 inflight during the previous year. They were all experienced aviators with pilot qualifications in multiple aircraft and had an average of 3163 total flight hours. However, none had UH-60 flight time. One of the four volunteers had participated in a previous USAARL research study.

Environmental conditions

Time averaged simulator temperature and humidity in the environmental chamber during simulated pre-flight treadmill walks were 100 °F and 20 percent RH. Likewise, these measures in the UH-60 simulator during test sessions were 100 °F and 50 percent RH, respectively. There was tight control of the environmental condition with actual temperature and humidity values deviating negligibly from levels prescribed in the research protocol.

Endurance

Crew endurance was defined as the interval of time from starting the preflight simulation on the treadmill to exiting the simulator due to mission completion, signs or symptoms of worsening heat exhaustion, test subject request to exit, medical monitor directive, or reaching the maximum permissible core temperature (102.5 °F) or heart rate. The pilots were all allowed to continue to their individual heat stress tolerance limits as long as core temperature and heart rate did not exceed prescribed termination thresholds and symptoms were not regarded by the medical monitor as excessive. They were withdrawn individually rather than as crews. The test subjects, however, were generally able to complete test sessions simultaneously as crews when wearing MCC. Endurance with MCC was significantly greater than without MCC since the mean endurance times for without MCC fell outside the 95% CI for with MCC means as illustrated in figures 3 and 4 below. The specific endurance times are provided in figure 5.

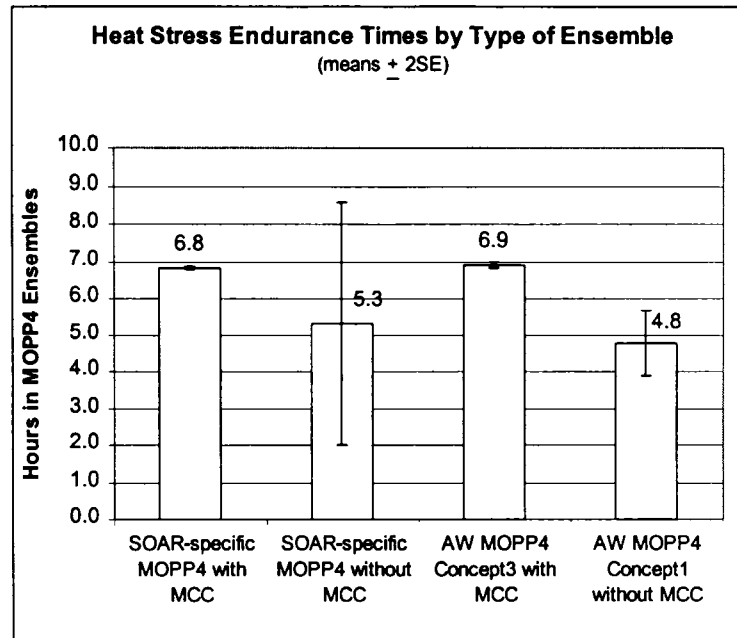


Figure 3. Aviator heat stress endurance by type of MOPP4 ensemble.

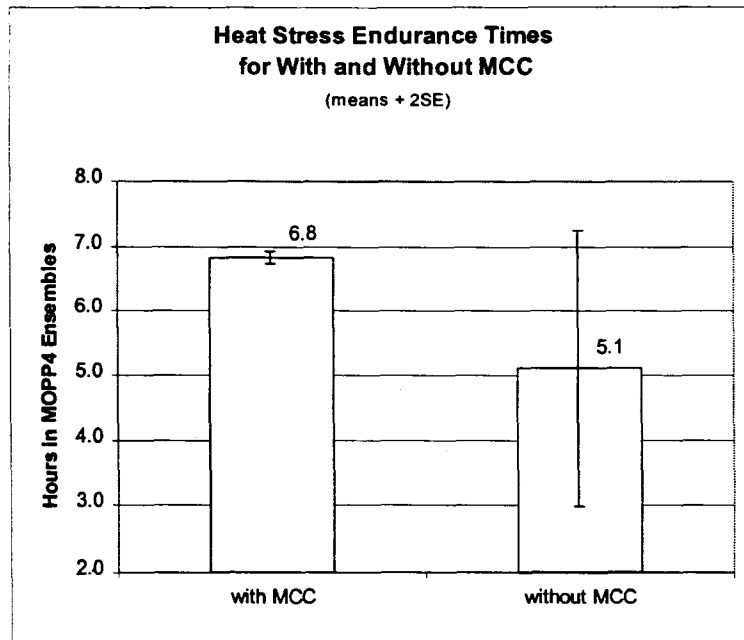


Figure 4. Heat stress endurance by with and without MCC.

| Hours in uniform | | | | |
|------------------|---------|----------|----------|----------|
| | SC | SX | AC | AX |
| TS#: 1 | 6.78 | 6.72 | 6.92 | NA |
| 2 | 6.78 | 6.72 | NA | 5.00 |
| 3 | 6.82 | 3.83 | NA | 4.55 |
| 4 | 6.82 | 3.92 | 6.88 | NA |
| AVG --> | 6.80 | 5.30 | 6.90 | 4.78 |
| 2*SD --> | 0.03849 | 3.281979 | 0.04714 | 0.636396 |
| 2*SE --> | 0.03849 | 3.281979 | 0.066667 | 0.9 |

| Hours in uniform | |
|------------------|-------------------|
| with MCC | without MCC |
| 6.8 | 6.7 |
| 6.8 | 6.7 |
| 6.8 | 3.8 |
| 6.8 | 3.9 |
| 6.9 | 5.0 |
| 6.9 | 4.6 |
| AVG --> | 6.83 5.12 |
| 2*SD --> | 0.109545 2.614036 |
| 2*SE --> | 0.089443 2.134352 |

NB: Ensembles

SC SOAR-specific MOPP4 with MCC
 SX SOAR-specific MOPP4 without MCC
 AC AW MOPP4 Concept3 with MCC
 AX AW MOPP4 Concept1 without MCC

Figure 5. Tabulation of endurance times by specific MOPP4 ensemble.

Physiological results

Core temperature

Mean core temperature profiles for the four ensembles, as functions of minutes into test session, are depicted in figure 6 (Appendix E). Figure 7 confirms that use of the MCC garment significantly lowered mean core temperature compared to ensembles without MCC. Figure 8 shows the relative increment in core temperature when not using MCC over the ensembles that included MCC. Note that the ordinate variable is the number of 10-minute increments, not minutes directly. Therefore, when averaged across ensembles with and without MCC, core temperature increased 0.0458 °F per 10 minutes, or 0.2748 °F per hour faster for the two ensembles that did not include MCC. The R^2 value indicates that the regression line accounts for 74% of the variance in core temperature differences. Figure 9 is a chart depicting the relative clustering of endurance and end test session core temperature by ensemble and use of MCC.

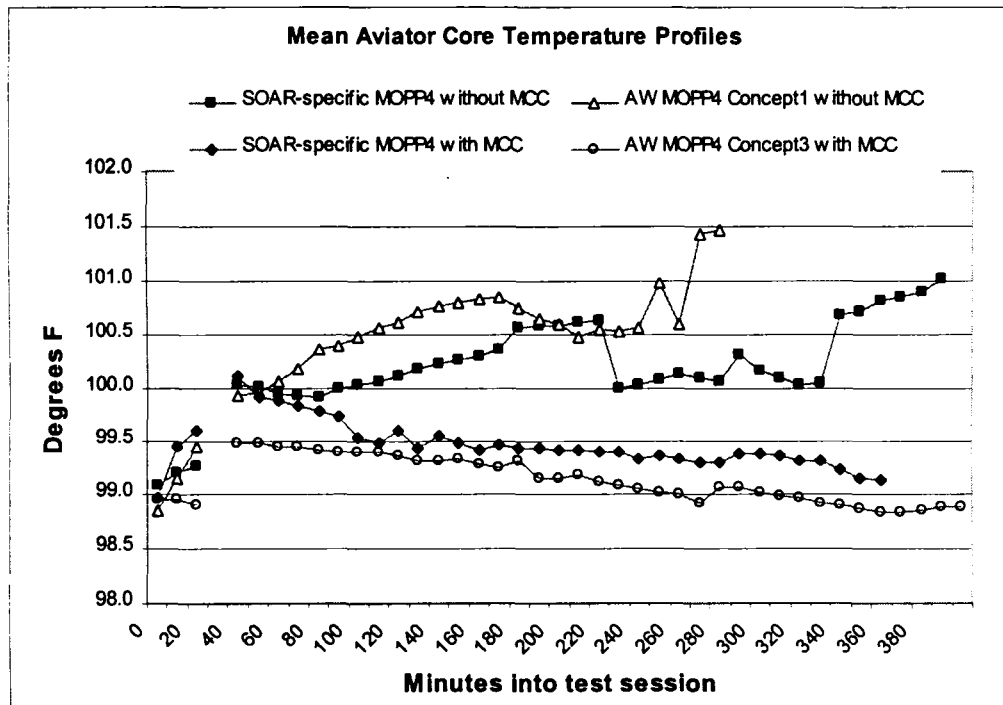


Figure 6. Core (rectal) temperature as functions of time by MOPP4 ensemble.
N.B.: data discontinuities between 30-50 minutes were due to treadmill-simulator transitions.

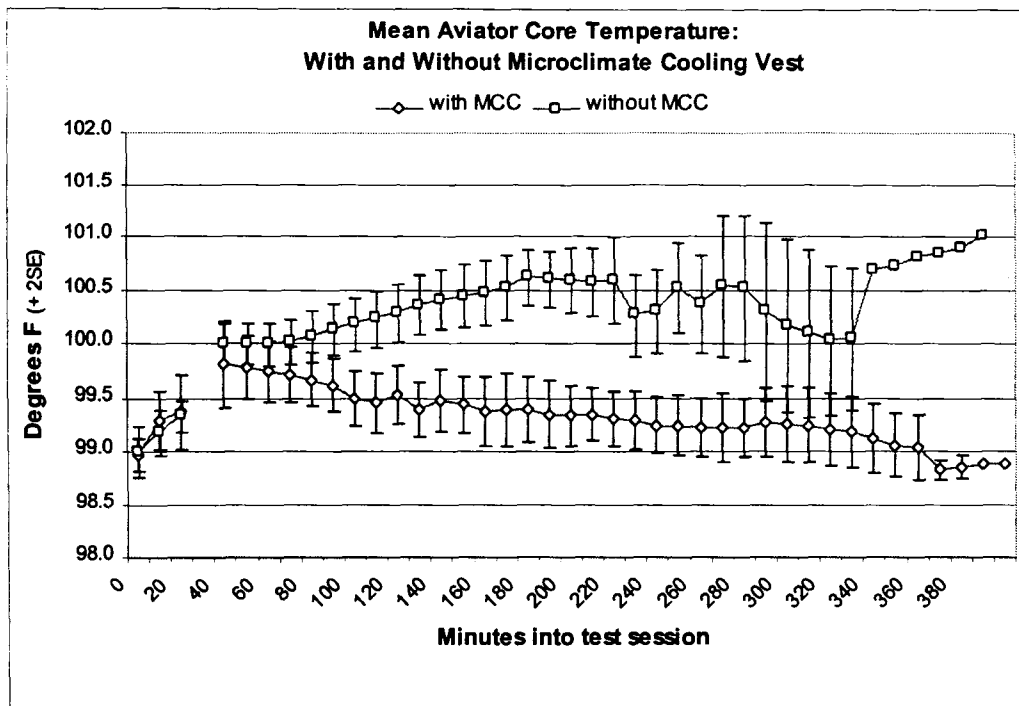


Figure 7. Core temperature as functions of time by with and without MCC.

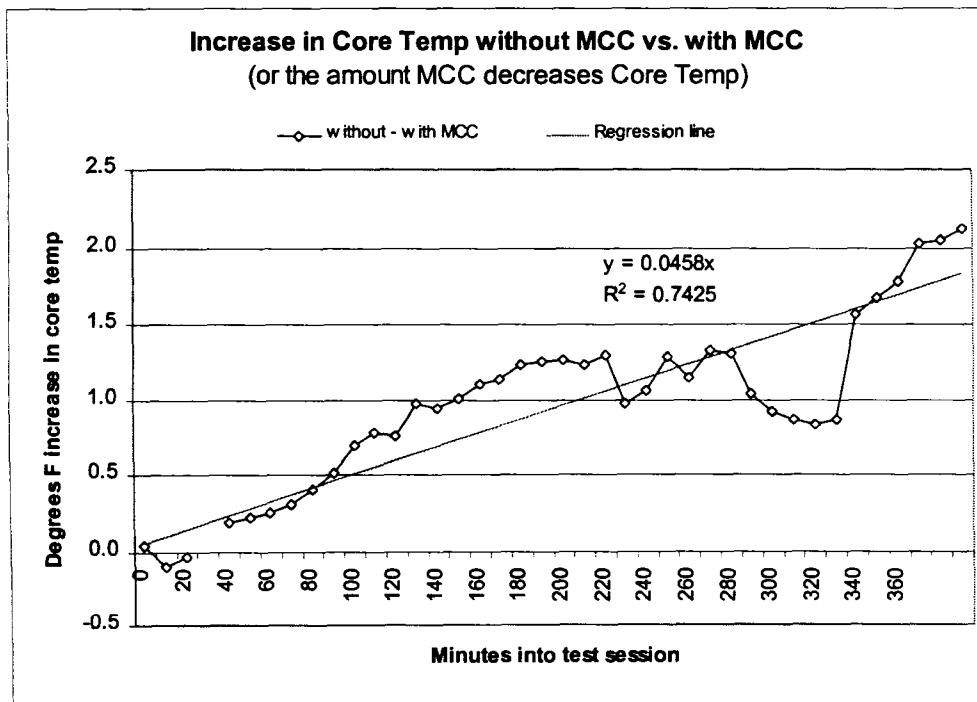


Figure 8. The relative increase in core (rectal) temperature when MCC is not used.

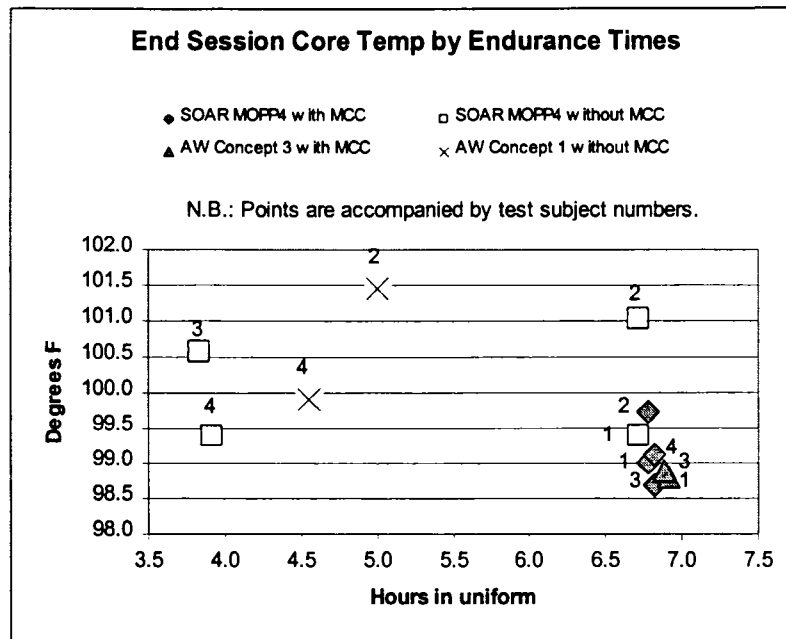


Figure 9. Endurance and end-session core (rectal) temperature by ensemble and test subject. Values in the right lower corner indicate better performance than those in the left upper corner.

Heart rate

Mean heart rate profiles for the four ensembles, as functions of minutes into test session, are depicted in figure 10 (also see Appendix F). Figure 11 confirms that use of the MCC garment significantly lowered mean heart rate response compared to ensembles without MCC. Figure 12 shows the relative increment in heart rate when not using MCC compared to heart rate responses for ensembles that included MCC. Note that the ordinate variable (x) in the regression equation is number of 10-minute increments, not minutes directly. Because of the logarithmic nature of the regression curve, heart rate (y) increases at a rate that is proportional to the inverse of time into test session ($9.53.8/x$ °F per number of 10 minute increments). The R^2 value indicates that the regression line accounts for 54% of the variance in heart rate differences. Figure 13 is a chart depicting the relative clustering of endurance and end test session heart rate by ensemble and use of MCC.

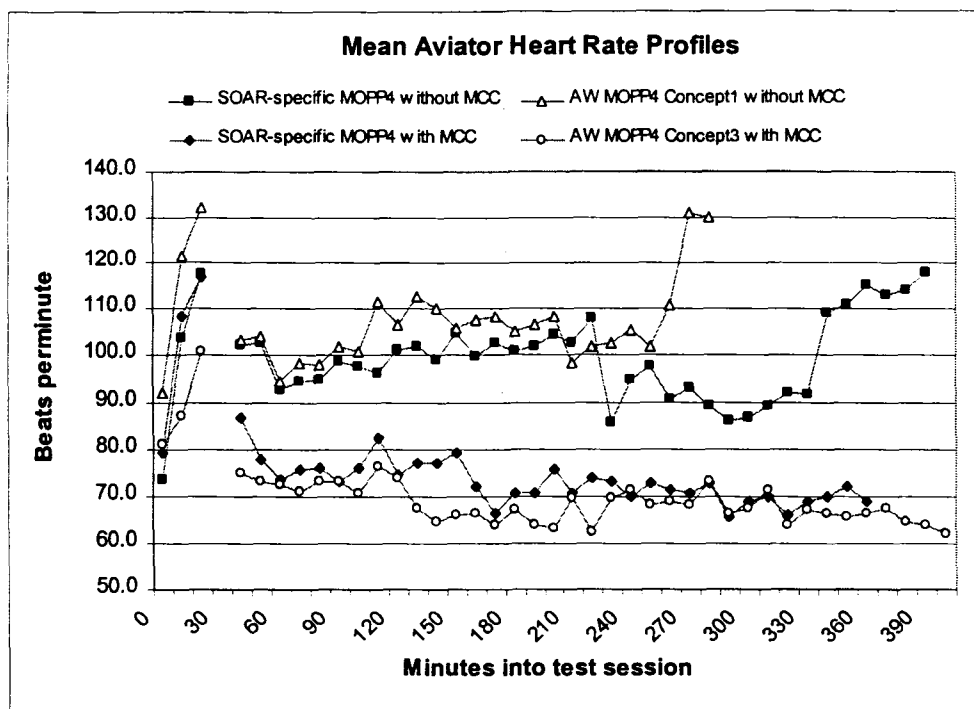


Figure 10. Heart rate as functions of time by MOPP4 ensemble.
N.B.: data discontinuities between 30-50 minutes were due to treadmill-simulator transitions.

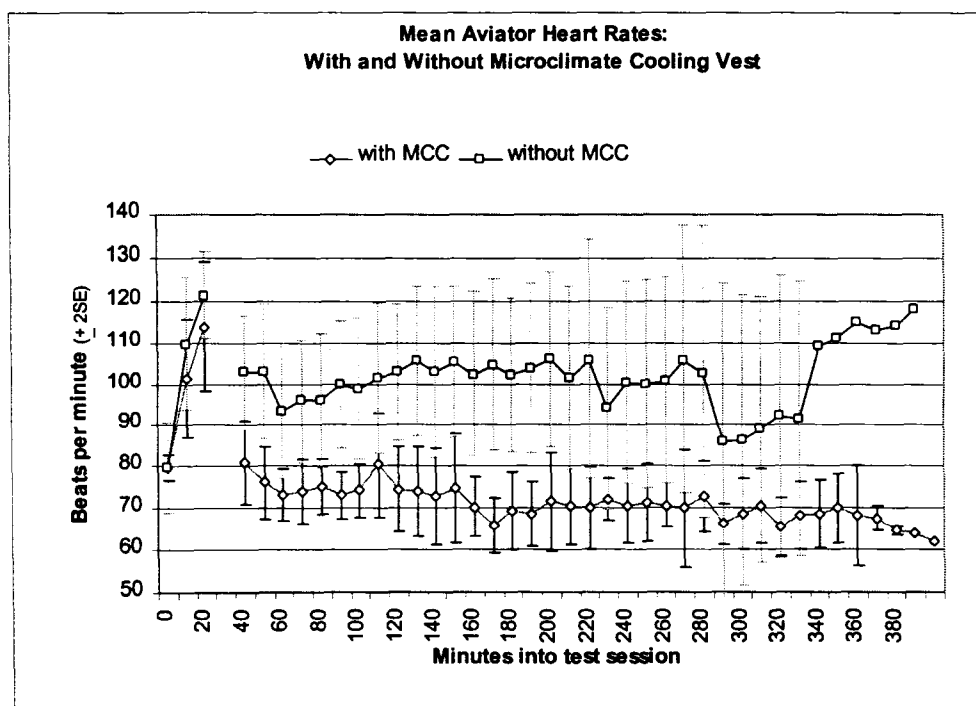


Figure 11. Heart rates as functions of test session duration by with and without MCC.

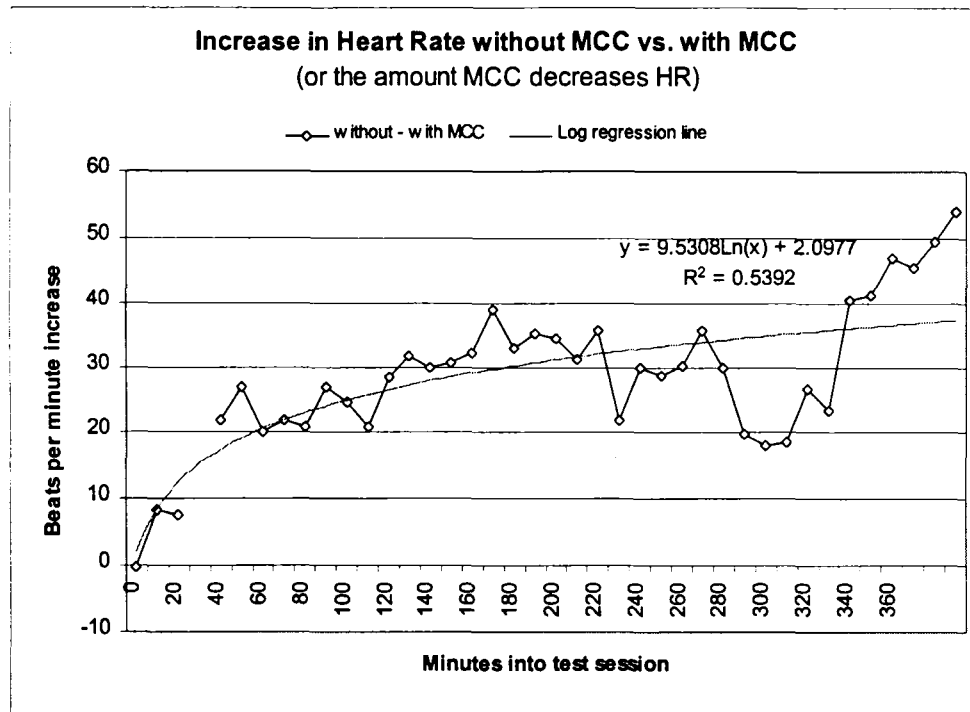


Figure 12. The relative increase in heart rate when MCC was not used.

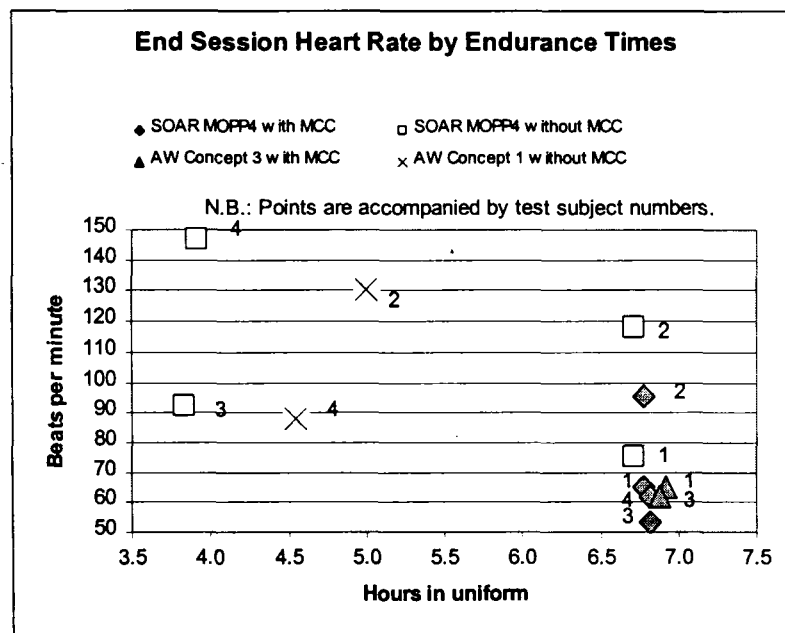


Figure 13. Endurance and end-session heart rate by ensemble and test subject.

Skin temperatures

Mean skin (anterior chest, upper lateral arm, mid lateral thigh, and mid lower calf) temperature responses for the four ensembles are depicted as functions of minutes in the simulator in figure 14. It is visually apparent that use of MCC resulted in lower arm and chest skin temperature but did not have much effect on thigh and calf temperatures.

Skin temperature profiles as functions of time in the simulator are aggregated in figure 15 by with and without microclimate cooling undershirt. These highlight the increased core to skin temperature gradient caused by wearing the MCC under-shirt.

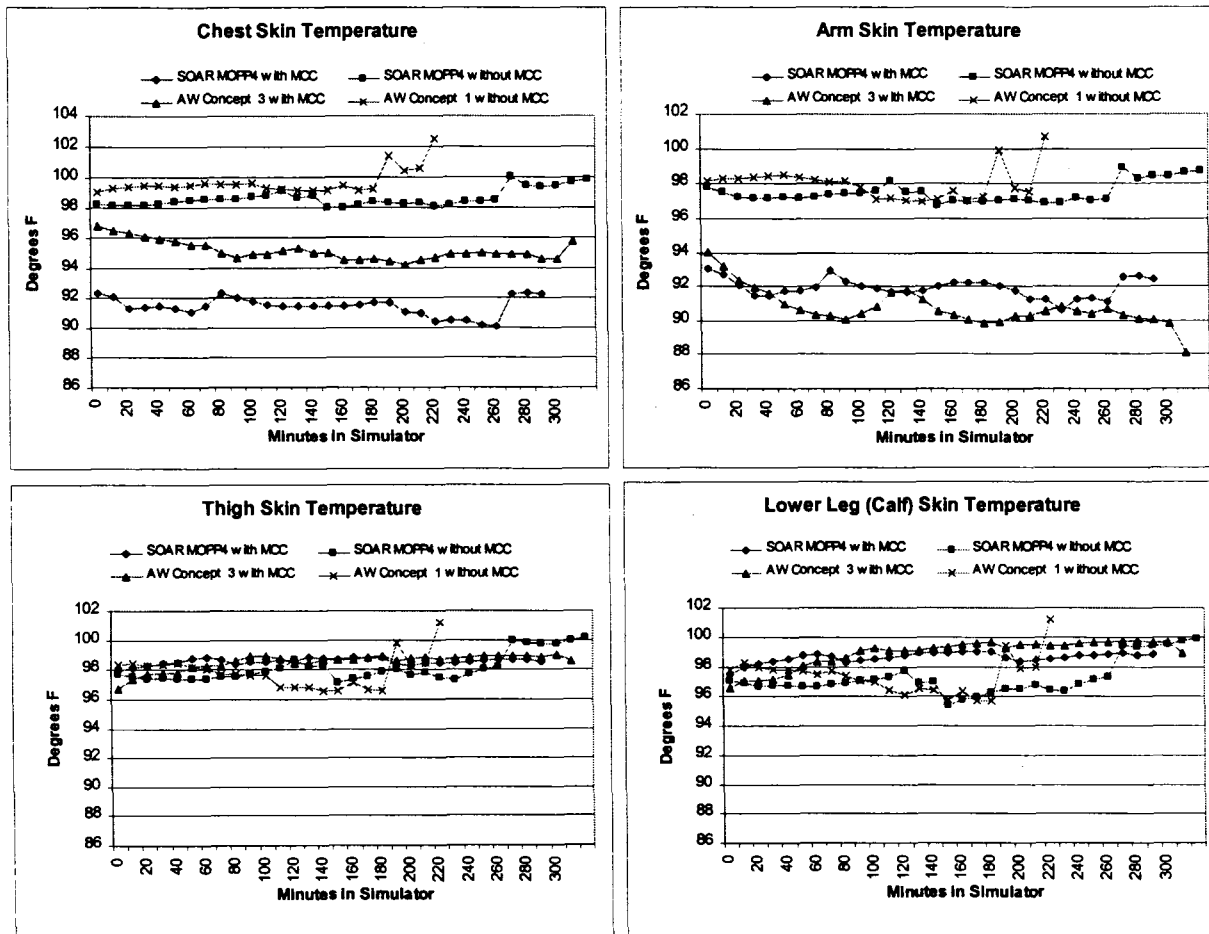


Figure 14. Mean chest, arm, thigh, and lower leg (calf) skin temperatures as functions of time in UH-60 simulator heat stress.

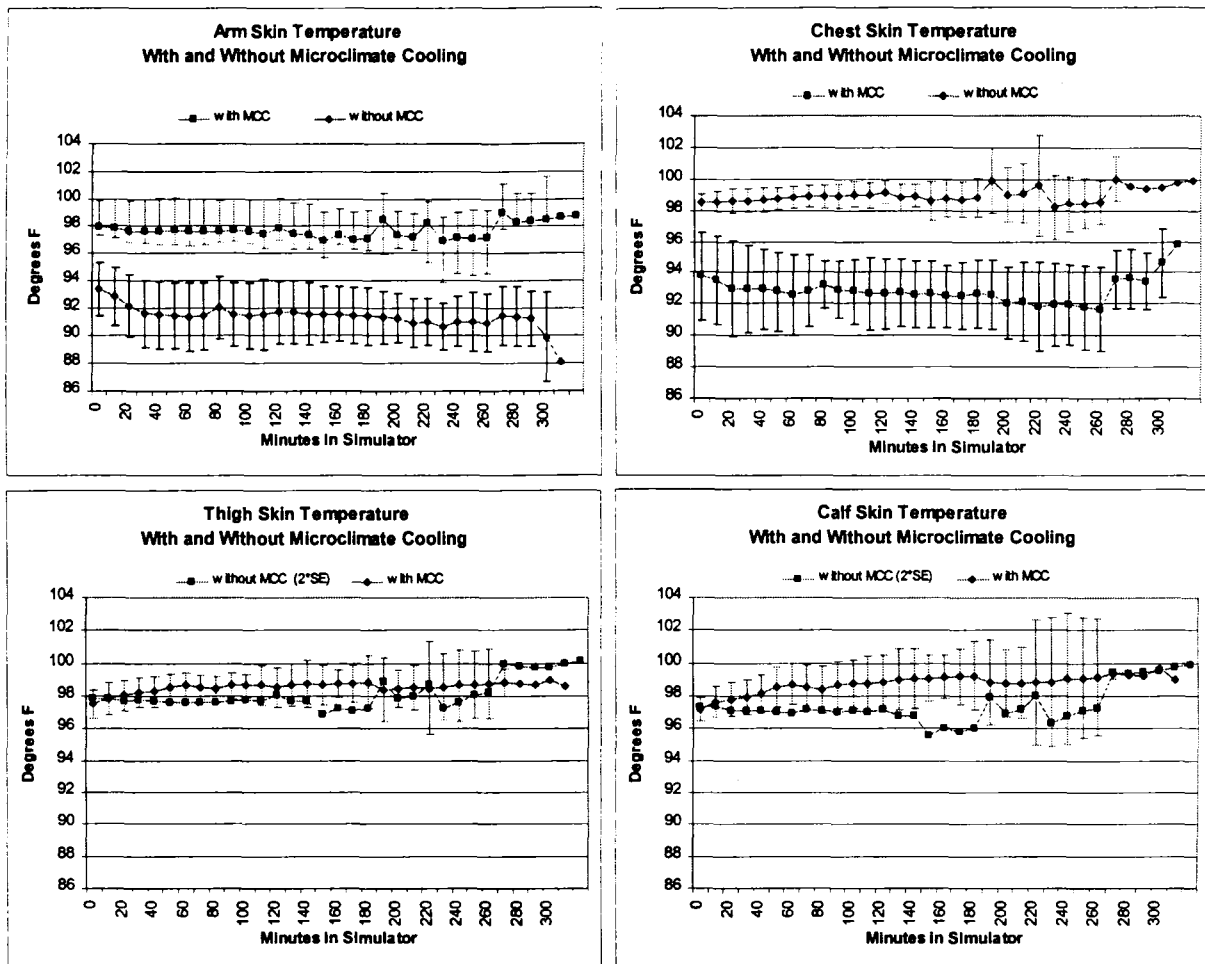


Figure 15. Mean chest, arm, thigh, and lower leg (calf) skin temperature as functions of time in UH-60 simulator heat stress, aggregated by with and without microclimate cooling.

An incidental finding was an apparent trend toward (paradoxically) elevated lower extremity skin temperature when using MCC. This could have been due to a relative decrease in skin bloodflow from MCC-reduced cardiac output from less heat strain. Alternatively, the MCC undershirt might, somehow, have caused or contributed to reduced venous return from the lower extremities. Such mechanisms could reduce vascular convective transfer of heat from the skin of the lower extremities. However, it is also possible that this was a factitious finding due to uncontrolled nonphysiological factors such as differences in seating position that may have preferentially shaded the legs from the heat lamps when aviators used MCC.

Fluid balance and dehydration

Figure 16 shows that use of MCC significantly reduced total and evaporated sweat losses (see also Appendix G). Water intake was concomitantly less in those sessions. MCC, however, seemed to increase urine output slightly. This might have been due to MCC inhibition of upper torso thermoregulatory cutaneous vasodilatation and could be significant for planning inflight urine containment and disposal systems, particularly since use of MCC can result in longer duration missions. Urine output rate of 300 ml/hour for a 6-hour sortie for example, results in a total urine output of close to two liters.

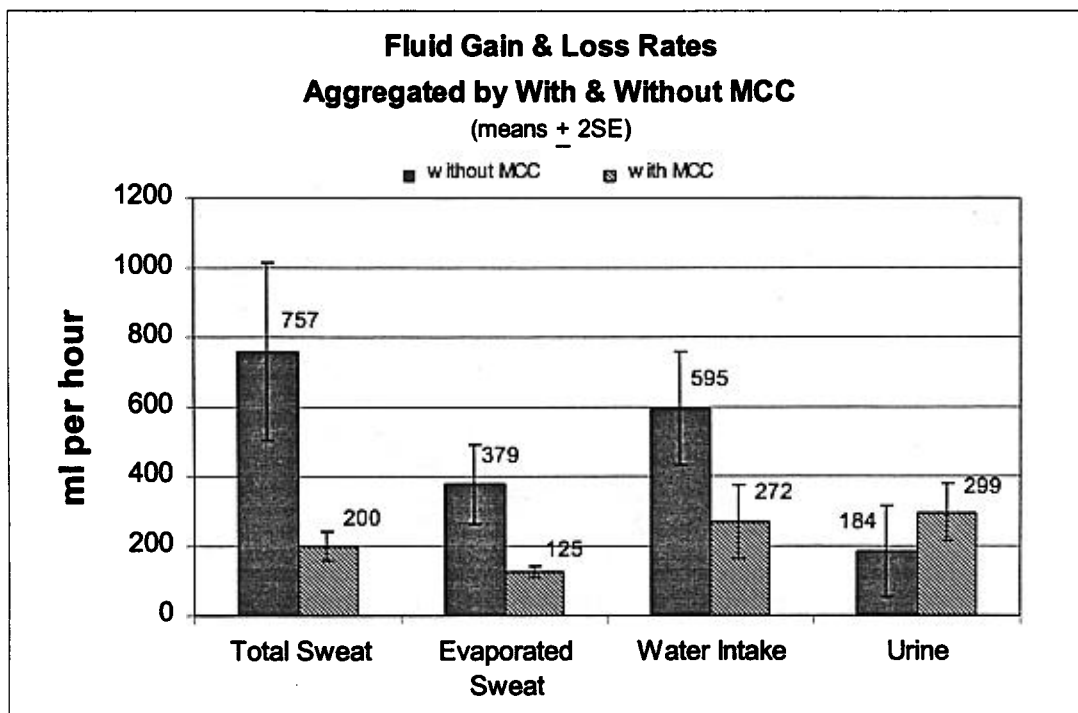


Figure 16. Fluid gain and loss rates (ml/hour) by with and without MCC.

Fluid intake deficit rates were calculated as the difference between fluid loss rates (sweat rate + urine output rate) and fluid intake rate. The results, depicted in figure 17, reveal that the largest fluid intake deficit rates were associated with the AW Concept 1 MOPP4 ensemble without MCC. This occurred for two reasons: the higher sweat rates and greater difficulty imbibing water for the pilots wearing that ensemble. Water intake deficit rates in the other ensembles were comparable, although the lowest deficit rate occurred with the SOAR-specific MOPP4 with MCC.

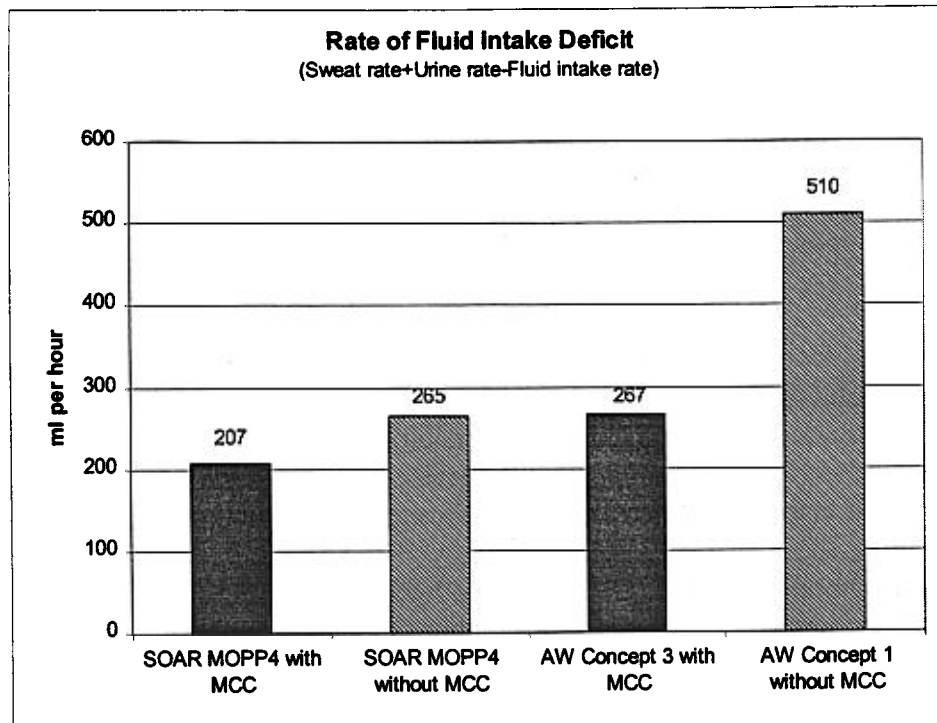


Figure 17. Rate of fluid intake deficit by ensemble.

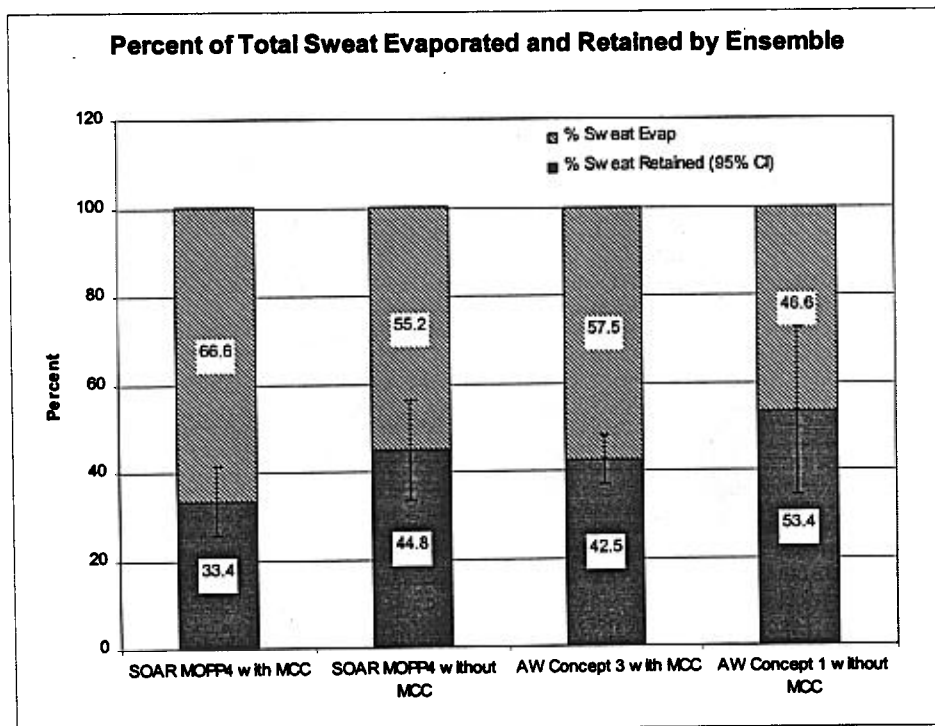


Figure 18. Percent of total sweat evaporated and retained by type of MOPP4 ensemble.

It should be noted, however, that even a seemingly small fluid intake deficit rate of 200 ml/hour could be significant. For example, during a 6-hour sortie, crewmembers would return to base with a 1200 cc water intake deficit. This represents 1.5% dehydration for a 180 pound aviator. Similarly, a fluid intake deficit rate of 500 ml/hour over a 6-hour sortie would mean an end-mission water intake deficit of 3 liters or 3.7% dehydration increment for a 180 pound aviator. If an aviator starts out slightly dehydrated (e.g., 1-1.5%), these additional increments in dehydration could, in themselves, cause symptoms and impair cognitive and physical performance.

Weight and fluid measurements were obtained so that the percent of total sweat that was evaporated versus retained in the uniform could be reported. The results are depicted in figure 18. Use of MCC was associated with a higher percentage of evaporated sweat, or conversely lower percentage of sweat retained. The SOAR-specific ensemble with MCC had the highest percentage of sweat evaporated whereas the AW Concept 1 without MCC had the lowest value.

Percent sweat evaporation results are aggregated by with and without MCC in figure 19 below. Presumably, since the MCC undershirt reduced total sweat rates, a greater percentage evaporated through the garment layers, whereas the higher sweat rates without MCC caused sweat to saturate the garment layers before reaching the outer surface where evaporation could occur.

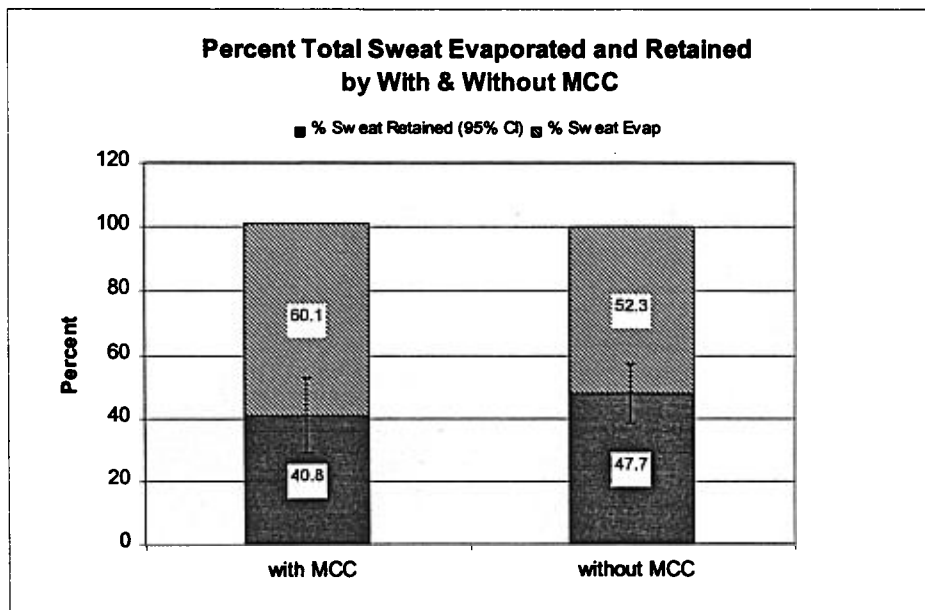


Figure 19. Percent of total sweat evaporated by with and without MCC.

Microclimate cooling system

The water-cooled microclimate system performed well without major mechanical problems during the test week. Cooling power was not directly measured due to lack of sensors to obtain cooling shirt flow rates and coolant temperatures during test sessions. However, analysis of sweat rate differences allowed an indirect estimate of the heat removal rates provided by the cooling undershirt. Cooling power was calculated by the differences between sweat rates (in liters/hr) without and with the MCC shirt multiplied by 0.580 kcal/ml of sweat (the approximate evaporative heat capacity of one ml of sweat). The results are shown in figure 20 below. The estimated cooling power of the MCC undershirt varied from 79.8 to 640 kcal/hr with a mean of 323 kcal/hr.

| Individual Total Sweat Rate (Ml/hr) | SOAR | SOAR | SOAR | SOAR | AW | AW | AVG | SE | 2*SE |
|---|--------------|-------------|--------------|--------------|--------------|--------------|--------------|-------------|--------------|
| with MCC | 212.0 | 280.1 | 137.6 | 167.5 | 221.8 | 183.9 | 200.5 | 20.2 | 40.4 |
| without MCC | 602.1 | 417.8 | 721.0 | 1271.0 | 556.4 | 971.4 | 756.6 | 127.9 | 255.8 |
| Estimated Cooling Rate (kcal/hr) | 226.3 | 79.8 | 338.4 | 640.0 | 194.1 | 456.8 | 322.6 | 82.4 | 164.8 |

NB: based on 580kcal potential evaporative cooling power per liter of sweat.

Figure 20. Estimated cooling power of the MCC shirt based on sweat rate differences. (AW with and without MCC represent the AW Concept 3 & 1 ensembles, respectively.)

Psychological results

Mood and symptoms

As indicated in figure 21, mean aviator ratings for most mood and symptom questions were significantly lower for the pilots wearing MCC (SC, AC) compared to when they were in the ensembles without MCC (SX, AX). The only ratings that were higher with MCC were those for perceived energy and boredom.

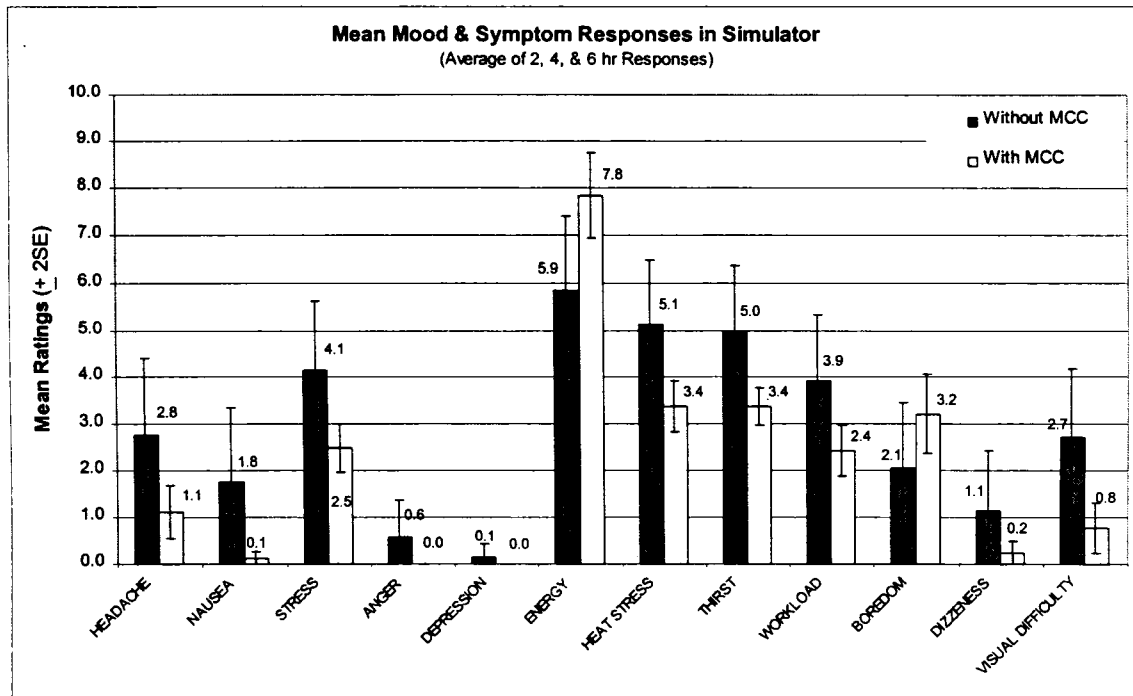


Figure 21. Mood and symptom questionnaire responses by with and without MCC.

Rating the aviator ensembles

An unweighted ranking method was used to objectively compare the heat stress performance of the four MOPP4 aviator ensembles. Mean values for endurance, physiological variables, sweat rate, and mood and symptom questionnaire responses were given integer ratings from 1 to 4 with 1 representing the best performing ensemble and 4 representing the worst performing ensemble. Averages of these MOP-rankings were then obtained for each ensemble. The 27 selected MOP means and rankings are listed in figure 22 and graphically depicted in figures 23 and 24.

| Mean by Type of MOPP4 Aviator Ensemble | | | | | Ranking of Means (1=best, 4=worst) | | | |
|--|------------------------------|---------------------------------|----------------------------|-------------------------------|------------------------------------|---------------------------------|----------------------------|-------------------------------|
| | SOAR-specific MOPP4 with MCC | SOAR-specific MOPP4 without MCC | AW MOPP4 Concept3 with MCC | AW MOPP4 Concept1 without MCC | SOAR-specific MOPP4 with MCC | SOAR-specific MOPP4 without MCC | AW MOPP4 Concept3 with MCC | AW MOPP4 Concept1 without MCC |
| Endurance (hours) | 6.80 | 5.30 | 6.90 | 4.78 | 2 | 5 | 1 | 4 |
| End pre-flight HR (bpm) | 117 | 118 | 101 | 132 | 2 | 3 | 1 | 4 |
| End simulator HR (bpm) | 69 | 118 | 62 | 130 | 2 | 3 | 1 | 4 |
| Core temp (simulated pre-flight) | 99.6 | 99.3 | 98.9 | 99.5 | 4 | 2 | 1 | 3 |
| Core temp (UH-60 simulator) | 99.1 | 101.0 | 98.9 | 101.5 | 2 | 3 | 1 | 4 |
| Arm skin temp (UH-60 simulator) | 91.9 | 97.5 | 90.7 | 98.0 | 2 | 3 | 1 | 4 |
| Chest skin temp (UH-60 simulator) | 91.4 | 98.6 | 95.2 | 99.7 | 1 | 3 | 2 | 4 |
| Sweat rate (ml/hr) | 199 | 753 | 203 | 764 | 1 | 3 | 2 | 4 |
| Questionnaire responses: | | | | | | | | |
| Headache | 1.3 | 1.6 | 0.8 | 5.8 | 2 | 3 | 1 | 4 |
| Nausea | 0.2 | 1.7 | 0.0 | 2.0 | 2 | 3 | 1 | 4 |
| Stress | 2.3 | 3.2 | 2.8 | 6.5 | 1 | 3 | 2 | 4 |
| Anger | 0.0 | 0 | 0.0 | 2.0 | 1 | 1 | 1 | 2 |
| Depression | 0.0 | 0 | 0.0 | 0.5 | 1 | 1 | 1 | 2 |
| Energy | 7.9 | 6.8 | 7.7 | 3.5 | 1 | 3 | 2 | 4 |
| Heat Stress | 3.6 | 4.4 | 3.0 | 7.0 | 2 | 3 | 1 | 4 |
| Thirst | 3.6 | 4.7 | 3.0 | 5.8 | 2 | 3 | 1 | 4 |
| Workload | 2.4 | 3 | 2.5 | 6.3 | 1 | 3 | 2 | 4 |
| Boredom | 2.8 | 2.1 | 4.0 | 2.0 | 3 | 2 | 4 | 1 |
| Dizziness | 0.3 | 1.3 | 0.2 | 0.8 | 2 | 4 | 1 | 3 |
| Visual Difficulty | 0.6 | 1.5 | 1.2 | 5.8 | 1 | 3 | 2 | 4 |
| Hot Spot Ratings: | | | | | | | | |
| Head | 4.2 | 4.0 | 3.1 | 7.6 | 3 | 2 | 1 | 4 |
| Chest | 0.3 | 0.8 | 0.0 | 5.5 | 2 | 3 | 1 | 4 |
| Back | 0.0 | 0.7 | 0.0 | 5.5 | 1 | 2 | 1 | 3 |
| Buttocks | 3.8 | 4.3 | 4.3 | 8.8 | 1 | 2 | 2 | 3 |
| Arm | 0.2 | 1.1 | 0.0 | 4.5 | 2 | 3 | 1 | 4 |
| Leg | 0.4 | 1.2 | 2.2 | 4.3 | 1 | 2 | 3 | 4 |
| Other | 1.6 | 1.2 | 1.0 | 2.5 | 3 | 2 | 1 | 4 |

Figure 22. Means and rankings for MOPs by ensemble.

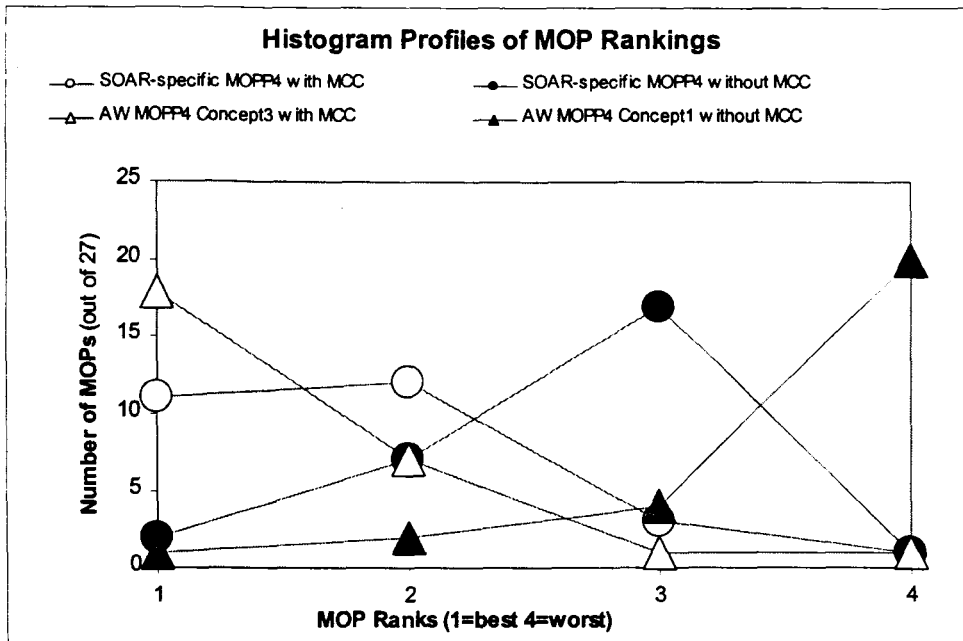


Figure 23. Histogram profiles of MOP rankings by ensemble.

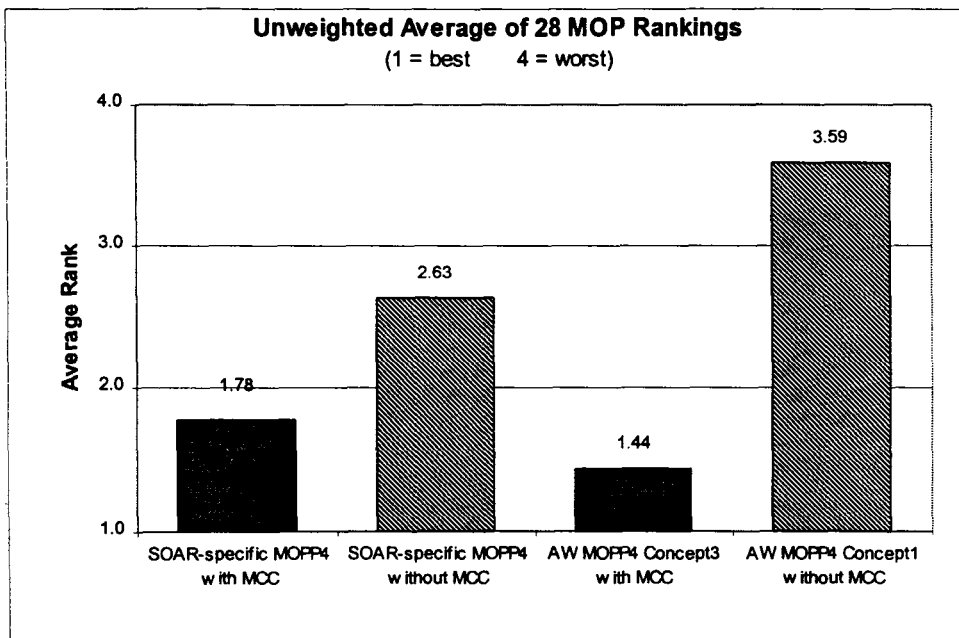


Figure 24. Unweighted average of MOP rankings by ensemble.

Discussion

This study determined physiological, mood, and symptom responses for U.S. Army helicopter pilots exposed to a significant level of heat stress (WBGT = 90 °F) in an environmentally controlled UH-60 simulator while wearing SOAR and Air Warrior MOPP4 aviator ensembles with and without a circulating water cooled undershirt. Results showed that the water-cooled microclimate system prolonged simulator flight times and significantly reduced physiological and psychological indicators of heat strain. The cooling shirt effectively maintained aviator body temperature and heart rate near preexposure baseline levels. Its use also was associated with significantly lower sweat rates and less heat stress-related discomfort. Conversely, a time-dependent progression of adverse heat stress symptoms was noted when MCC was not used.

The results of ranking 27 heat stress performance variables indicated that the Air Warrior Concept 3 MOPP4 ensemble with MCC had the best heat stress mitigation effects followed by (in order of decreasing heat stress performance) the SOAR-specific MOPP4 with MCC, SOAR-specific MOPP4 without MCC, and Air Warrior Concept 1 MOPP4 ensemble without MCC.

Although sweat rates were reduced by the water cooled undershirt, the prolonged mission endurance would necessitate that each aviators start similar real scenarios with 2 – 3 liters of potable water. Likewise, for extended helicopter operations over hot desert areas, crews should ensure that supplementary emergency potable water is onboard and readily accessible in the event a forced landing is required. As a complementary measure, urine containment devices of sufficient capacity (e.g., 2-3 liters per crewmember for a 6-hour mission) should be available to reduce the tendency of crews on extended missions to intentionally restrict water intake to avoid the distracting discomfort of progressively distended bladders.

We also recommend that aircraft microclimate cooling systems include easy-to-use flow-rate and temperature controls as well as a backup system if the primary microclimate cooling system fails. Allowing crewmember cooling rate control is essential since cockpit temperatures can vary considerably over relatively short periods of time due to weather changes, temperature lapse rate associated with climbing to high altitudes, terrain effects, and diurnal changes. It is also reasonable to propose dual-mode MCC systems that could pump warm water to keep crewmembers comfortable when exposed to low ambient temperatures associated with transitioning from day to night or low to high altitude operations.

Finally, microclimate cooling systems should be designed and built for long mean time between failure (MTBF). This is an essential consideration since an MCC system failure effectively results in a passive, thermally occlusive, clothing layer that restricts the effectiveness of physiological heat loss mechanism. Therefore, a nonfunctioning cooling undergarment will exacerbate heat stress.

Conclusions

This comparison of SOAR and AW Concept 1 and 3 aviator MOPP4 ensembles using a realistic, 6-hour, hot weather UH-60 scenario indicated best performance in heat stress by the AW Concept 3 MOPP4 ensemble with MCC. That ensemble performed somewhat better than the SOAR MOPP4 ensemble with MCC. The SOAR MOPP4 ensemble performed better than AW Concept 1 MOPP4 without MCC. However, since the AW Concept 3 ensemble was not tested without MCC it was not possible to determine whether that combination would provide better heat stress tolerance than SOAR MOPP4 without MCC in situations where MCC is not available. Additionally, ensembles rankings could differ if the MOPs were weighted in proportion to actual or perceived differences in importance with respect to operational or managerial factors. Nonetheless, in this study, the beneficial heat stress reduction effects of MCC were unequivocal and consistent with previous research.

Our results indicated that the undershirt MCC system should be effective in reducing heat strain in similar real-world operational heat stress conditions. The composite physiological responses to heat stress and MCC were consistent with previous research. However, the comparative ensemble rankings may not be statistically robust due to the small number of test subjects, mixed-design, limitations that prevented pretest training and acclimatization to the extent desired, and lack of full counterbalancing. If this data is to serve as the basis for important or costly development and acquisition decisions, it may be advisable to verify the stability of the numerical differences between the aviator ensembles with additional evaluations.

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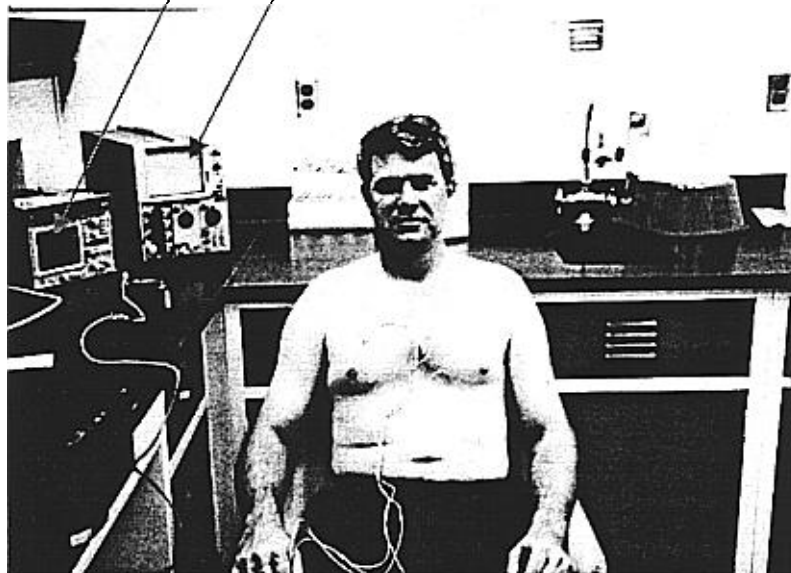
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Appendix A.

Study process photos.

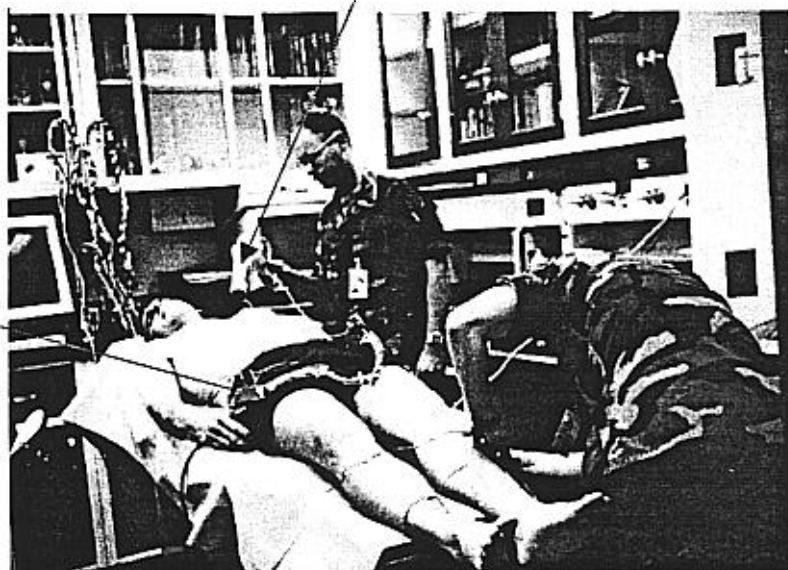
ECG monitor to evaluate waveform and confirm heart rate.
Oscilloscope to confirm heart rate counter R-wave capture.



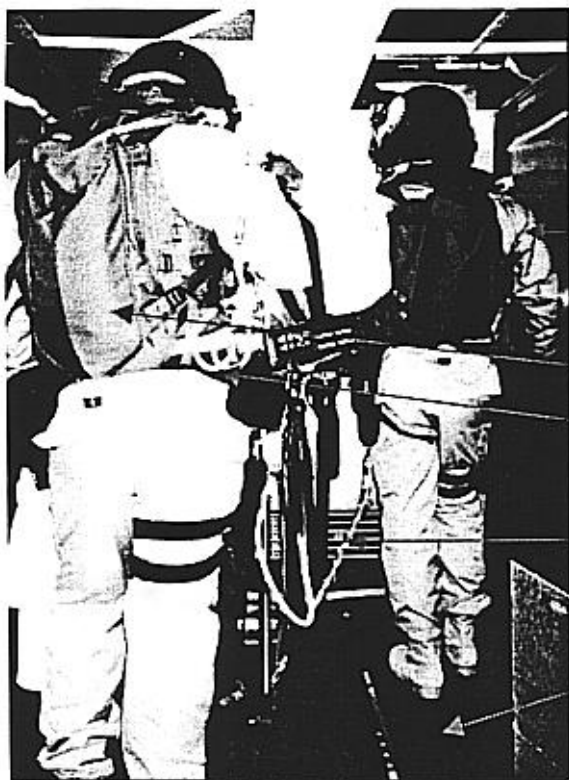
ECG sensors arranged to maximize lead II R-wave amplitude.

SSG Jones drying the colloidian affixing the skin temperature sensors prior to securing them with tape

Taped bundle of sensor wires



Application of skin temperature sensors



SOAR MOPP4 aviator
ensemble with MCC

Piggy Bac drinking water

Cooling shirt tubing

Sensor harness

Treadmill

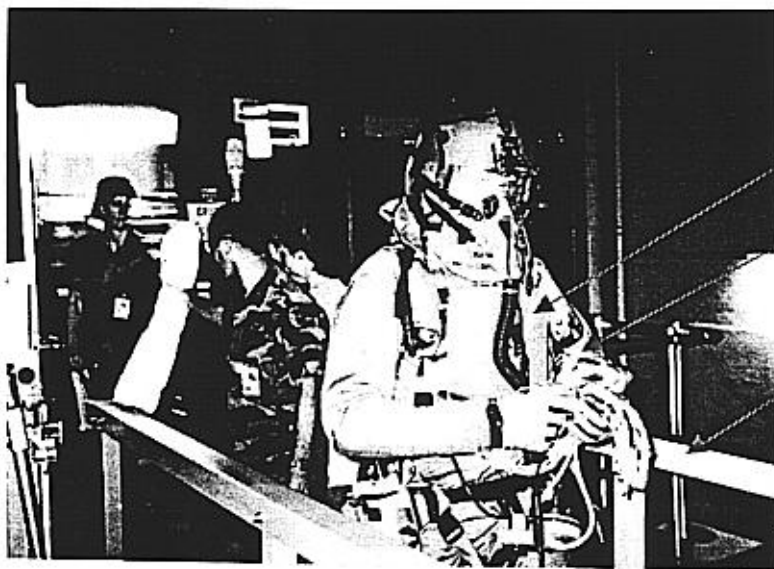
Test subjects on treadmill in environmental chamber

Backup ECG monitor

Digital heart rate and core temperature readings



Research assistant, SSG Brock, recording data in the simulator.



Ballistic plate

AW Concept 3 MOPP4
aviator ensemble with MCC

Drop bridge to
simulator

Test subject exiting the environmentally controlled UH-60 simulator.

Keyboard for setup
and control

Touch-sensitive
simulator sortie
monitoring and
control display



Simulator operator CW2 Swanberg.



Research psychologist,
CPT Katz, ensuring
accurate post-session
weights

Centered and properly
seated scale.

Obtaining fully clothed weight after exiting simulator.



Test subject heart
rates and
temperatures

SSG Jones checking
camera views of test
subjects

Remote test subject monitoring station.

Appendix B.

Tested ensembles with component and total weights.

160th SOAR-Specific

| Item | Average Weight(kg) |
|--|---------------------------|
| HGU-56/PHelmet | 1.626 |
| Communication Earplug | 0.010 |
| Flight suit 2pc Nomex | 0.930 |
| Combat Boots | 1.631 |
| Kneeboard (soft wrap-around type) | 0.815 |
| Utility ("bat") belt w/first aid kit | 2.813 |
| Soft Body Armor | 4.382 |
| Spectra plate | 1.482 |
| Chemical vapor protective glove (Gentex 8475-12-330) | 0.116 |
| Chemical protective sock | 0.134 |
| 2-pc chemical protective undergarment | 1.526 |
| MBA-19/P AERPS CB mask | 0.878 |
| ILC-Dover Blower | 0.498 |
| Microclimate Climate Cooling Shirt | 0.764 |
| Piggy bac water container | 0.813 |
| Total (kg) → | 18.418 kg |



Top part of MCC unit: cooling & pump

Bottom part of MCC unit: batteries

Piggy bac 2-liter water container

SOAR 2-piece flight suit

Bundled sensor wires



SOAR-specific MOPP4 Aviator Ensemble: Front and Side Views

Air Warrior Concept 1

| Item | Weight (kg) |
|--|-------------|
| HGU-56/P Helmet | 1.626 |
| Communication Earplug | 0.010 |
| Flight suit 1pc Nomex | 0.872 |
| Combat boots | 1.631 |
| Flight gloves GS/FRP2 summer weight | 0.088 |
| Survival Harness vest: AirSave w/core survival items | 4.404 |
| Ballistic Vest: (std. AirSave, soft body armor) | 4.896 |
| Ballistic plate: Spectra plate | 1.482 |
| Chemical vapor protective gloves:Paul Boye' | 0.088 |
| Chemical protective sock | 0.208 |
| 2-pc chemical protective undergarment | 1.526 |
| M45 CB mask | 0.866 |
| CH20 Lightweight motor blower | |
| Life vest: Low profile flotation | 1.278 |
| LRU-37/P Raft | 2.310 |
| Heed w/remote mouth piece | 1.058 |
| Total (kg) → | 22.343 kg |



HGU-56/P helmet

Nomex 1-piece flight suit

CH2O mask blower

LRU-37/P raft

Portable data logger



Air Warrior Concept I MOPP4 Aviator Ensemble: Front and Back Views



Low profile floatation life vest

Survival vest over ballistic vest and plate

Chemical protective 2-piece undergarment worn as part of AW Concept 1 and SOAR ensembles but not AW Concept 3

Chemical protective socks



Air Warrior Concept I MOPP4 Aviator Ensemble: Additional Views

Air Warrior Concept 3

| Item | Weight(kg) |
|--|-------------------|
| HGU-56/P Helmet | 1.626 |
| Communication Earplug | 0.010 |
| Flight suit: Anti-exposure coveralls CWU-62B/P | 1.478 |
| Combat boots | 1.631 |
| Survival harness/vest: SEI harness | 4.404 |
| Soft Body Armor: BEAU 1 | 3.868 |
| Ballistic plate: Spectra plate | 1.482 |
| Chemical vapor protective gloves | 0.118 |
| CB mask | 0.894 |
| Blowers | 0.488 |
| Life vest: LPU-34/P low profile | 1.278 |
| Raft: LRU-18/P-SeaPack | 4.436 |
| Heed w/remote mouth piece | 1.058 |
| Flight gloves GS/FRP2 summer weight | 0.088 |
| Total (kg) → | 22.771 kg |



HGU-56/P helmet

CWU-62B/P anti-exposure/
chemical protective 1-piece flight
suit

Integral butyl-rubber neck piece

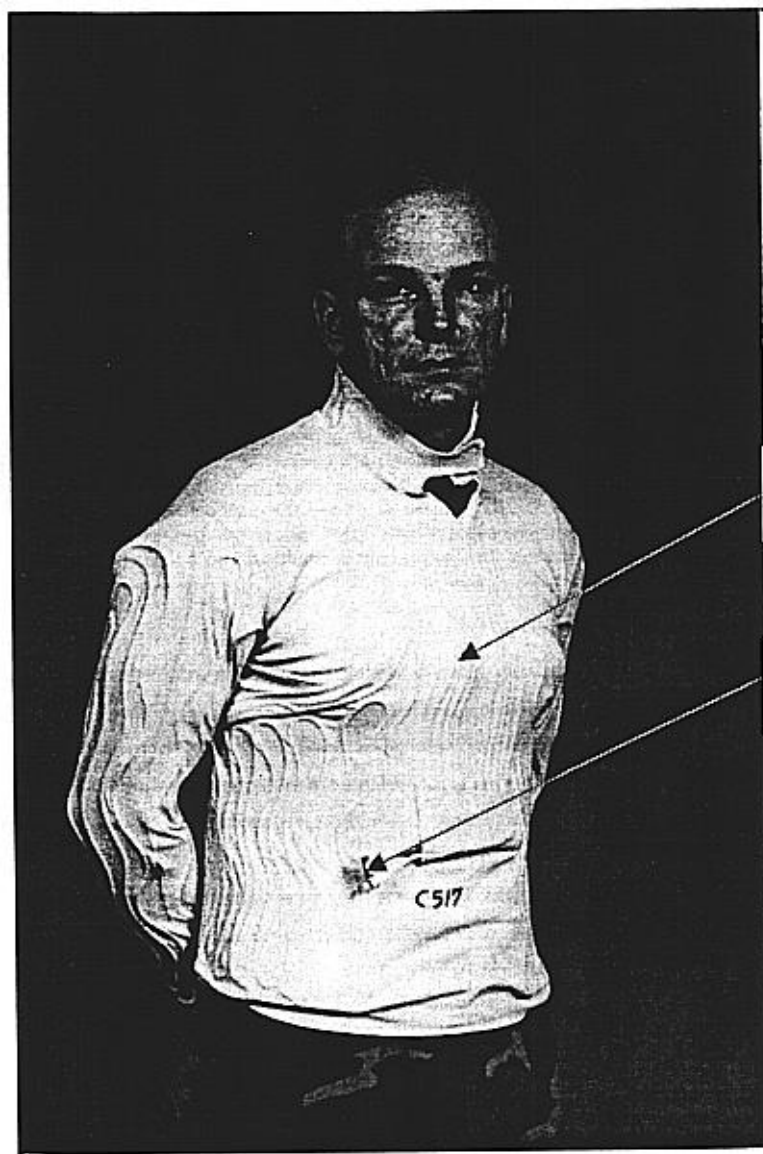
Clam-shell zipper for donning
the 1-piece suit



Air Warrior Concept 3 MOPP4 Aviator Ensemble: Frontal Views

Appendix C.

Microclimate cooling system.



Cooling tubes between layers
of the undergarment

Input/output cooling tube
connectors

Microclimate cooling (PVCS) undershirt



Portable Vapor-Compression Cooling System (PVCS)

Overview:

The **Portable Vapor-Compression Cooling System (PVCS)** is a self-contained man-portable microclimate cooling system designed to provide wearers of insulative protective clothing with cooling to reduce the effects of heat stress.

Description:

The PVCS consists of the Refrigeration Unit, Battery Module, Heat Transfer Garment, and accessory tether lines. The Refrigeration Unit chills the coolant and pumps it through the External Coolant Tether Line and into the Heat Transfer Garment. Metabolic heat from the body is transferred to the coolant as it flows through the network of tubing in the Heat Transfer Garment. The coolant then flows back to the Refrigeration Unit where the heat is rejected. The Battery Module can be disconnected and detached from the Refrigeration Unit if a DC power supply is available.

Specifications:

- Cooling capacity (Battery Mode): 1200 Watt-hours (300 Watts cooling rate)
- Comfortable cooling temperature at 65°-70° Fahrenheit
- Four-hour duration on batteries, indefinitely on 24 Volt vehicle power
- Compact size (Refrigeration Unit 416 in³, Battery Module 450 in³)
- Full body cooling through liquid cooling shirt, pants, & hood
- Energy efficient (6 Amps max. at 24 Volts)
- Refrigeration Unit Type: Vapor Compression (HFC, R-134a refrigerant)
- Battery Module: four BA5590 lithium sulfur dioxide batteries
- Refrigeration Unit Weight: 10 lbs.
- Battery Module Weight: 11 lbs.
- Heat Transfer Garment (Shirt, pants, & hood) Weight: 6 lbs.

Status:

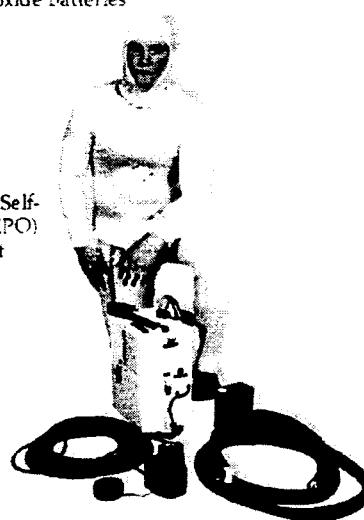
The PVCS has been successfully field tested with the Self-Contained Toxic Environments Protective Outfit (STEPO) ensemble. It has also been favorably evaluated in heat stress induced physiological studies in climatically controlled chambers.

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or

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N8025J10 rev 1-21-98

Appendix D.

Test subject demographics data.

Baseline Test Subject Demographic and Training Data

| Test Subject | 1 | 2 |
|---|-------------------|----------------------------|
| Rank | CW4 | CW2 |
| Gender | MALE | MALE |
| Have you ever been a test subject before? | NO | YES |
| What aircraft are you rated in? | UH-1, OH-58, MH-6 | OH-58, CH-47, MH-47, TH-67 |
| Additional aviator qualifications | NONE | NONE |
| Total flight hours as a pilot | 5000 | 650 |
| UH-60 pilot flight hours | 0 | 0 |
| UH-60 simulator pilot hours | 0 | 0 |
| NBC overgarment and mask past year (hrs) | 0 | 2 |
| NBC overgarment and mask past 5 years (hrs) | 3 | 0 |
| Age | 41 | 30 |
| Height (inches) | 70 | 71 |
| Weight (pounds) | 192 | 186 |
| Most recent PT test | Nov-97 | Dec-97 |
| Pushups | 73 | 75 |
| Situps | 75 | 90 |
| Run time | 13:40 | 13:30 |
| How many times per week you do PT? | 7 | 5 |
| Total hrs of physical training per week | 9.5 | 5 |
| Total hrs training in heat casualty over past two years | 2 | 3 |

| Test Subject | 3 | 4 |
|---|---------------------------------|--------------|
| Rank | CW4 | CW3 |
| Gender | MALE | MALE |
| Have you ever been a test subject before? | NO | NO |
| What aircraft are you rated in? | TH-55, UH-1, OH-58, MH-6, MH-47 | MH-47E, UH-1 |
| Additional aviator qualifications | MASTER AVIATOR | IP |
| Total flight hours as a pilot | 4500 | 2500 |
| UH-60 pilot flight hours | 0 | 0 |
| UH-60 simulator pilot hours | 0 | 0 |
| NBC overgarment and mask past year (hrs) | 6 | 0 |
| NBC overgarment and mask past 5 years (hrs) | 30 | 2 |
| Age | 48 | 39 |
| Height (inches) | 73 | 74 |
| Weight (pounds) | 192 | 219 |
| Most recent PT test | | Jun-98 |
| Pushups | | 73 |
| Situps | | 78 |
| Run time | | 14:25 |
| How many times per week you do PT? | 5 | 3 |
| Total hrs of physical training per week | 5 | 3 |
| Total hrs training in heat casualty over past two years | 4 | 4 |

Appendix E.

Core temperature data.

| SOAR-specific MOPP4 with MCC | | | | | | | |
|------------------------------|---------|---------|---------|---------|--------|-------|-------|
| Test date -> | 6/17/98 | 6/17/98 | 6/18/97 | 6/18/98 | | | |
| Ensemble -> SC | SC | SC | SC | SC | | | |
| Minutes/TS# --> | 1 | 2 | 3 | 4 Mean | 2*SD | 2*SE | |
| 0 | 99 | 99 | 98.7 | 99.2 | 98.98 | 0.412 | 0.206 |
| 10 | 99.5 | 99.6 | 99.1 | 99.6 | 99.45 | 0.476 | 0.238 |
| 20 | 99.5 | 99.7 | 99.4 | 99.8 | 99.60 | 0.365 | 0.183 |
| 30 | | | | | | | |
| 40 | 100.1 | 100.2 | | | 100.12 | 0.127 | 0.090 |
| 50 | 100.0 | 100.3 | 99.5 | 100.0 | 99.92 | 0.661 | 0.330 |
| 60 | 99.9 | 100.2 | 99.5 | 99.9 | 99.89 | 0.610 | 0.305 |
| 70 | 99.9 | 100.2 | 99.4 | 99.9 | 99.83 | 0.608 | 0.304 |
| 80 | 99.9 | 100.1 | 99.4 | 99.8 | 99.79 | 0.597 | 0.298 |
| 90 | 99.8 | 100.1 | 99.3 | 99.7 | 99.73 | 0.642 | 0.321 |
| 100 | 99.2 | 100.0 | 99.2 | 99.6 | 99.53 | 0.785 | 0.392 |
| 110 | 99.1 | 100.0 | 99.2 | 99.6 | 99.48 | 0.870 | 0.435 |
| 120 | 99.9 | 100.0 | 99.1 | 99.5 | 99.61 | 0.795 | 0.397 |
| 130 | 99.2 | 100.0 | 99.1 | 99.5 | 99.43 | 0.776 | 0.388 |
| 140 | 99.8 | 100.0 | 99.0 | 99.4 | 99.55 | 0.834 | 0.417 |
| 150 | 99.7 | 99.9 | 99.0 | 99.4 | 99.49 | 0.810 | 0.405 |
| 160 | 99.3 | 100.1 | 98.9 | 99.4 | 99.42 | 1.007 | 0.503 |
| 170 | 99.4 | 100.1 | 98.9 | 99.5 | 99.46 | 1.030 | 0.515 |
| 180 | 99.4 | 100.0 | 98.9 | 99.4 | 99.43 | 0.943 | 0.472 |
| 190 | 99.4 | 100.0 | 98.9 | 99.4 | 99.44 | 0.868 | 0.434 |
| 200 | 99.3 | 99.9 | 99.0 | 99.4 | 99.42 | 0.777 | 0.388 |
| 210 | 99.4 | 99.8 | 99.0 | 99.5 | 99.42 | 0.678 | 0.339 |
| 220 | 99.4 | 99.8 | 99.0 | 99.4 | 99.40 | 0.694 | 0.347 |
| 230 | 99.4 | 99.8 | 98.9 | 99.4 | 99.39 | 0.750 | 0.375 |
| 240 | 99.2 | 99.8 | 98.9 | 99.4 | 99.34 | 0.745 | 0.373 |
| 250 | 99.4 | 99.8 | 98.9 | 99.3 | 99.36 | 0.723 | 0.361 |
| 260 | 99.3 | 99.8 | 98.9 | 99.3 | 99.33 | 0.740 | 0.370 |
| 270 | 99.3 | 99.8 | 98.9 | 99.3 | 99.29 | 0.721 | 0.361 |
| 280 | 99.3 | 99.8 | 98.9 | 99.3 | 99.30 | 0.752 | 0.376 |
| 290 | 99.3 | 100.0 | 98.9 | 99.3 | 99.38 | 0.920 | 0.460 |
| 300 | 99.4 | 100.0 | 98.8 | 99.3 | 99.38 | 0.979 | 0.490 |
| 310 | 99.4 | 100.0 | 98.9 | 99.2 | 99.37 | 0.960 | 0.480 |
| 320 | 99.3 | 100.0 | 98.9 | 99.2 | 99.32 | 0.921 | 0.461 |
| 330 | 99.2 | 99.9 | 98.9 | 99.2 | 99.31 | 0.868 | 0.434 |
| 340 | 99.2 | 99.9 | 98.8 | 99.1 | 99.23 | 0.914 | 0.457 |
| 350 | 99.0 | 99.7 | 98.7 | 99.1 | 99.15 | 0.841 | 0.420 |
| 360 | 99.0 | 99.7 | 98.7 | 99.1 | 99.13 | 0.877 | 0.439 |
| 370 | | | | | | | |

| SOAR-specific MOPP4 without MCC | | | | | | | |
|---------------------------------|---------|---------|---------|---------|--------|-------|-------|
| Test date -> | 6/16/98 | 6/16/98 | 6/21/98 | 6/21/98 | | | |
| Ensemble -> | SX | SX | SX | SX | SX | SX | SX |
| TS# --> | 3 | 4 | 1 | 2 | Mean | 2*SD | 2*SE |
| 0 | 98.7 | 99.7 | 98.4 | 99.5 | 99.08 | 1.248 | 0.624 |
| 10 | 98.9 | 99.7 | 98.5 | 99.7 | 99.20 | 1.200 | 0.600 |
| 20 | 99.3 | 99.4 | 98.7 | 99.7 | 99.28 | 0.839 | 0.419 |
| 30 | | | | | | | |
| 40 | 100.0 | 100.6 | 99.3 | 100.2 | 100.03 | 1.118 | 0.559 |
| 50 | 100.0 | 100.7 | 99.3 | 100.1 | 100.01 | 1.161 | 0.581 |
| 60 | 99.9 | 100.6 | 99.1 | 100.1 | 99.95 | 1.239 | 0.619 |
| 70 | 100.0 | 100.6 | 99.1 | 100.1 | 99.94 | 1.233 | 0.616 |
| 80 | 100.0 | 100.7 | 99.0 | 99.9 | 99.91 | 1.371 | 0.686 |
| 90 | 100.0 | 100.8 | 99.1 | 100.1 | 100.00 | 1.421 | 0.711 |
| 100 | 100.1 | 100.8 | 99.1 | 100.1 | 100.03 | 1.454 | 0.727 |
| 110 | 100.1 | 100.9 | 99.1 | 100.2 | 100.07 | 1.497 | 0.749 |
| 120 | 100.1 | 101.0 | 99.1 | 100.3 | 100.12 | 1.558 | 0.779 |
| 130 | 100.2 | 101.1 | 99.2 | 100.3 | 100.19 | 1.558 | 0.779 |
| 140 | 100.2 | 101.1 | 99.2 | 100.4 | 100.23 | 1.621 | 0.811 |
| 150 | 100.2 | 101.2 | 99.1 | 100.5 | 100.26 | 1.700 | 0.850 |
| 160 | 100.3 | 101.3 | 99.1 | 100.5 | 100.29 | 1.756 | 0.878 |
| 170 | 100.3 | 101.3 | 99.2 | 100.6 | 100.36 | 1.793 | 0.897 |
| 180 | 100.4 | 101.4 | 99.6 | 100.9 | 100.56 | 1.569 | 0.785 |
| 190 | 100.4 | 101.4 | 99.5 | 100.9 | 100.58 | 1.638 | 0.819 |
| 200 | 100.5 | 101.6 | 99.4 | 100.9 | 100.59 | 1.857 | 0.928 |
| 210 | 100.6 | 101.7 | 99.3 | 100.9 | 100.62 | 1.948 | 0.974 |
| 220 | | 101.8 | 99.3 | 100.8 | 100.63 | 2.429 | 1.403 |
| 230 | | | 99.4 | 100.6 | 100.00 | 1.807 | 1.278 |
| 240 | | | 99.4 | 100.7 | 100.04 | 1.884 | 1.332 |
| 250 | | | 99.3 | 100.9 | 100.08 | 2.240 | 1.584 |
| 260 | | | 99.3 | 101.0 | 100.14 | 2.316 | 1.638 |
| 270 | | | 99.3 | 100.9 | 100.10 | 2.367 | 1.674 |
| 280 | | | 99.2 | 100.9 | 100.07 | 2.418 | 1.710 |
| 290 | | | 99.5 | 101.1 | 100.31 | 2.342 | 1.656 |
| 300 | | | 99.4 | 101.0 | 100.18 | 2.266 | 1.602 |
| 310 | | | 99.3 | 100.9 | 100.10 | 2.215 | 1.566 |
| 320 | | | 99.3 | 100.7 | 100.03 | 1.960 | 1.386 |
| 330 | | | 99.4 | 100.7 | 100.05 | 1.858 | 1.314 |
| 340 | | | | 100.7 | 100.69 | | |
| 350 | | | | 100.7 | 100.72 | | |
| 360 | | | | 100.8 | 100.81 | | |
| 370 | | | | 100.9 | 100.85 | | |
| 380 | | | | 100.9 | 100.90 | | |
| 390 | | | | 101.0 | 101.01 | | |

| AW MOPP4 Concept1 without MCC | | | | | |
|-------------------------------|---------|---------|--------|-------|-------|
| Test date -> | 6/19/98 | 6/20/98 | | | |
| | AX | AX | AX | AX | AX |
| TS# --> | 2 | 3 | Mean | 2*SD | 2*SE |
| 0 | 99.3 | 98.4 | 98.85 | 1.273 | 0.900 |
| 10 | 99.5 | 98.8 | 99.15 | 0.990 | 0.700 |
| 20 | 99.6 | 99.3 | 99.45 | | 0.300 |
| 30 | | | | | |
| 40 | 100.1 | 99.8 | 99.94 | 0.331 | 0.234 |
| 50 | 100.1 | 99.9 | 99.97 | 0.255 | 0.180 |
| 60 | 100.1 | 100.0 | 100.07 | 0.076 | 0.054 |
| 70 | 100.2 | 100.1 | 100.18 | 0.178 | 0.126 |
| 80 | 100.4 | 100.3 | 100.37 | 0.127 | 0.090 |
| 90 | 100.5 | 100.3 | 100.40 | 0.356 | 0.252 |
| 100 | 100.6 | 100.3 | 100.48 | 0.382 | 0.270 |
| 110 | 100.7 | 100.4 | 100.56 | 0.356 | 0.252 |
| 120 | 100.7 | 100.5 | 100.62 | 0.356 | 0.252 |
| 130 | 100.9 | 100.6 | 100.72 | 0.382 | 0.270 |
| 140 | 100.9 | 100.6 | 100.76 | 0.356 | 0.252 |
| 150 | 101.0 | 100.6 | 100.81 | 0.484 | 0.342 |
| 160 | 101.0 | 100.6 | 100.84 | 0.585 | 0.414 |
| 170 | 101.1 | 100.6 | 100.85 | 0.611 | 0.432 |
| 180 | 101.0 | 100.5 | 100.74 | 0.662 | 0.468 |
| 190 | 100.9 | 100.4 | 100.65 | 0.713 | 0.504 |
| 200 | 100.9 | 100.3 | 100.60 | 0.865 | 0.612 |
| 210 | 100.9 | 100.1 | 100.49 | 1.171 | 0.828 |
| 220 | 101.0 | 100.1 | 100.55 | 1.196 | 0.846 |
| 230 | 101.1 | 100.0 | 100.54 | 1.604 | 1.134 |
| 240 | 101.2 | 100.0 | 100.57 | 1.706 | 1.206 |
| 250 | 101.2 | 100.7 | 100.98 | 0.764 | 0.540 |
| 260 | 101.3 | 99.9 | 100.60 | 1.935 | 1.368 |
| 270 | 101.4 | | 101.43 | | |
| 280 | 101.5 | | 101.46 | | |
| 290 | | | | | |
| 300 | | | | | |
| 310 | | | | | |
| 320 | | | | | |
| 330 | | | | | |
| 340 | | | | | |
| 350 | | | | | |
| 360 | | | | | |
| 370 | | | | | |
| 380 | | | | | |
| 390 | | | | | |

| AW MOPP4 Concept3 with MCC | | | | | |
|-------------------------------|---------|---------|-------|-------|-------|
| Test date -> | 6/19/98 | 6/20/98 | | | |
| Ensemble -> | AC | AC | AC | AC | AC |
| TS# --> | 1 | 4 | Mean | 2*SD | 2*SE |
| 0 | 99.1 | 98.8 | 98.95 | 0.424 | 0.300 |
| 10 | 99.1 | 98.8 | 98.95 | 0.424 | 0.300 |
| 20 | 99.2 | 98.6 | 98.9 | 0.849 | 0.600 |
| 30 | | | | | |
| 40 | 99.3 | 99.7 | 99.49 | 0.585 | 0.414 |
| 50 | 99.3 | 99.7 | 99.49 | 0.535 | 0.378 |
| 60 | 99.3 | 99.6 | 99.45 | 0.458 | 0.324 |
| 70 | 99.3 | 99.6 | 99.46 | 0.331 | 0.234 |
| 80 | 99.3 | 99.5 | 99.42 | 0.229 | 0.162 |
| 90 | 99.3 | 99.5 | 99.40 | 0.229 | 0.162 |
| 100 | 99.4 | 99.4 | 99.40 | 0.127 | 0.090 |
| 110 | 99.4 | 99.4 | 99.40 | 0.076 | 0.054 |
| 120 | 99.3 | 99.4 | 99.37 | 0.076 | 0.054 |
| 130 | 99.3 | 99.4 | 99.32 | 0.102 | 0.072 |
| 140 | 99.3 | 99.4 | 99.32 | 0.153 | 0.108 |
| 150 | 99.3 | 99.4 | 99.33 | 0.127 | 0.090 |
| 160 | 99.2 | 99.4 | 99.28 | 0.229 | 0.162 |
| 170 | 99.2 | 99.4 | 99.26 | 0.280 | 0.198 |
| 180 | 99.3 | 99.4 | 99.31 | 0.127 | 0.090 |
| 190 | 99.0 | 99.3 | 99.16 | 0.407 | 0.288 |
| 200 | 99.0 | 99.3 | 99.15 | 0.382 | 0.270 |
| 210 | 99.1 | 99.3 | 99.18 | 0.305 | 0.216 |
| 220 | 99.1 | 99.2 | 99.11 | 0.127 | 0.090 |
| 230 | 99.1 | 99.1 | 99.09 | 0.102 | 0.072 |
| 240 | 99.0 | 99.1 | 99.05 | 0.102 | 0.072 |
| 250 | 99.0 | 99.1 | 99.01 | 0.153 | 0.108 |
| 260 | 98.9 | 99.1 | 99.00 | 0.204 | 0.144 |
| 270 | 98.9 | | 98.92 | | |
| 280 | 98.9 | 99.2 | 99.06 | 0.382 | 0.270 |
| 290 | 99.0 | 99.2 | 99.06 | 0.280 | 0.198 |
| 300 | 98.9 | 99.1 | 99.01 | 0.305 | 0.216 |
| 310 | 98.9 | 99.1 | 98.98 | 0.305 | 0.216 |
| 320 | 98.9 | 99.1 | 98.96 | 0.305 | 0.216 |
| 330 | 98.8 | 99.0 | 98.92 | 0.280 | 0.198 |
| 340 | 98.8 | 99.0 | 98.90 | 0.229 | 0.162 |
| 350 | 98.8 | 98.9 | 98.86 | 0.229 | 0.162 |
| 360 | 98.8 | 98.9 | 98.83 | 0.204 | 0.144 |
| 370 | 98.8 | 98.9 | 98.83 | 0.127 | 0.090 |
| 380 | 98.8 | 98.9 | 98.85 | 0.153 | 0.108 |
| 390 | | 98.9 | 98.89 | | |
| | | 98.9 | 98.89 | | |

| Ensemble TS # | With Microclimate Cooling | | | | | | *C Mean | *C 2*SD | *C 2*SE |
|------------------|---------------------------|---------|---------|---------|---------|---------|------------|------------|------------|
| | SC 1 | SC 2 | SC 3 | SC 4 | AC 1 | AC 4 | | | |
| 0 | 99 | 99 | 98.7 | 99.2 | 99.1 | 98.8 | 99.0 | 0.372 | 0.152 |
| 10 | 99.5 | 99.6 | 99.1 | 99.6 | 99.1 | 98.8 | 99.3 | 0.662 | 0.270 |
| 20 | 99.5 | 99.7 | 99.4 | 99.8 | 99.2 | 98.6 | 99.4 | 0.864 | 0.353 |
| 30 | | | | | | | | | |
| 40 | 100.1 | 100.2 | | | 99.3 | 99.7 | 99.8 | 0.806 | 0.403 |
| 50 | 100.0 | 100.3 | 99.5 | 100.0 | 99.3 | 99.7 | 99.8 | 0.717 | 0.293 |
| 60 | 99.9 | 100.2 | 99.5 | 99.9 | 99.3 | 99.6 | 99.7 | 0.691 | 0.282 |
| 70 | 99.9 | 100.2 | 99.4 | 99.9 | 99.3 | 99.6 | 99.7 | 0.630 | 0.257 |
| 80 | 99.9 | 100.1 | 99.4 | 99.8 | 99.3 | 99.5 | 99.7 | 0.608 | 0.248 |
| 90 | 99.8 | 100.1 | 99.3 | 99.7 | 99.3 | 99.5 | 99.6 | 0.608 | 0.248 |
| 100 | 99.2 | 100.0 | 99.2 | 99.6 | 99.4 | 99.4 | 99.5 | 0.624 | 0.255 |
| 110 | 99.1 | 100.0 | 99.2 | 99.6 | 99.4 | 99.4 | 99.5 | 0.679 | 0.277 |
| 120 | 99.9 | 100.0 | 99.1 | 99.5 | 99.3 | 99.4 | 99.5 | 0.666 | 0.272 |
| 130 | 99.2 | 100.0 | 99.1 | 99.5 | 99.3 | 99.4 | 99.4 | 0.613 | 0.250 |
| 140 | 99.8 | 100.0 | 99.0 | 99.4 | 99.3 | 99.4 | 99.5 | 0.691 | 0.282 |
| 150 | 99.7 | 99.9 | 99.0 | 99.4 | 99.3 | 99.4 | 99.4 | 0.651 | 0.266 |
| 160 | 99.3 | 100.1 | 98.9 | 99.4 | 99.2 | 99.4 | 99.4 | 0.801 | 0.327 |
| 170 | 99.4 | 100.1 | 98.9 | 99.5 | 99.2 | 99.4 | 99.4 | 0.835 | 0.341 |
| 180 | 99.4 | 100.0 | 98.9 | 99.4 | 99.3 | 99.4 | 99.4 | 0.743 | 0.303 |
| 190 | 99.4 | 100.0 | 98.9 | 99.4 | 99.0 | 99.3 | 99.3 | 0.755 | 0.308 |
| 200 | 99.3 | 99.9 | 99.0 | 99.4 | 99.0 | 99.3 | 99.3 | 0.687 | 0.280 |
| 210 | 99.4 | 99.8 | 99.0 | 99.5 | 99.1 | 99.3 | 99.3 | 0.600 | 0.245 |
| 220 | 99.4 | 99.8 | 99.0 | 99.4 | 99.1 | 99.2 | 99.3 | 0.615 | 0.251 |
| 230 | 99.4 | 99.8 | 98.9 | 99.4 | 99.1 | 99.1 | 99.3 | 0.663 | 0.271 |
| 240 | 99.2 | 99.8 | 98.9 | 99.4 | 99.0 | 99.1 | 99.2 | 0.651 | 0.266 |
| 250 | 99.4 | 99.8 | 98.9 | 99.3 | 99.0 | 99.1 | 99.2 | 0.668 | 0.273 |
| 260 | 99.3 | 99.8 | 98.9 | 99.3 | 98.9 | 99.1 | 99.2 | 0.675 | 0.275 |
| 270 | 99.3 | 99.8 | 98.9 | 99.3 | 98.9 | | 99.2 | 0.707 | 0.316 |
| 280 | 99.3 | 99.8 | 98.9 | 99.3 | 98.9 | 99.2 | 99.2 | 0.657 | 0.268 |
| 290 | 99.3 | 100.0 | 98.9 | 99.3 | 99.0 | 99.2 | 99.3 | 0.797 | 0.326 |
| 300 | 99.4 | 100.0 | 98.8 | 99.3 | 98.9 | 99.1 | 99.3 | 0.858 | 0.350 |
| 310 | 99.4 | 100.0 | 98.9 | 99.2 | 98.9 | 99.1 | 99.2 | 0.860 | 0.351 |
| 320 | 99.3 | 100.0 | 98.9 | 99.2 | 98.9 | 99.1 | 99.2 | 0.818 | 0.334 |
| 330 | 99.2 | 99.9 | 98.9 | 99.2 | 98.8 | 99.0 | 99.2 | 0.797 | 0.325 |
| 340 | 99.2 | 99.9 | 98.8 | 99.1 | 98.8 | 99.0 | 99.1 | 0.796 | 0.325 |
| 350 | 99.0 | 99.7 | 98.7 | 99.1 | 98.8 | 98.9 | 99.1 | 0.723 | 0.295 |
| 360 | 99.0 | 99.7 | 98.7 | 99.1 | 98.8 | 98.9 | 99.0 | 0.751 | 0.307 |
| 370 | | | | | 98.8 | 98.9 | 98.8 | 0.127 | 0.090 |
| 380 | | | | | 98.8 | 98.9 | 98.9 | 0.153 | 0.108 |
| 390 | | | | | | 98.9 | 98.9 | | |
| | | | | | | 98.9 | 98.9 | | |

| Ensemble TS # | Without Microclimate Cooling | | | | | | *X | *X | *X |
|------------------|------------------------------|---------|---------|---------|---------|---------|--------|-------|-------|
| | SX 3 | SX 4 | SX 1 | SX 2 | AX 2 | AX 3 | Mean | 2*SD | 2*SE |
| 0 | 98.7 | 99.7 | 98.4 | 99.5 | 99.3 | 98.4 | 99.00 | 1.145 | 0.234 |
| 10 | 98.9 | 99.7 | 98.5 | 99.7 | 99.5 | 98.8 | 99.18 | 1.031 | 0.210 |
| 20 | 99.3 | 99.4 | 98.7 | 99.7 | 99.6 | 99.3 | 99.33 | 0.700 | 0.143 |
| 30 | | | | | | | | | |
| 40 | 100.0 | 100.6 | 99.3 | 100.2 | 100.1 | 99.8 | 100.00 | 0.883 | 0.180 |
| 50 | 100.0 | 100.7 | 99.3 | 100.1 | 100.1 | 99.9 | 100.00 | 0.908 | 0.185 |
| 60 | 99.9 | 100.6 | 99.1 | 100.1 | 100.1 | 100.0 | 99.99 | 0.967 | 0.197 |
| 70 | 100.0 | 100.6 | 99.1 | 100.1 | 100.2 | 100.1 | 100.02 | 0.989 | 0.202 |
| 80 | 100.0 | 100.7 | 99.0 | 99.9 | 100.4 | 100.3 | 100.07 | 1.165 | 0.238 |
| 90 | 100.0 | 100.8 | 99.1 | 100.1 | 100.5 | 100.3 | 100.13 | 1.187 | 0.242 |
| 100 | 100.1 | 100.8 | 99.1 | 100.1 | 100.6 | 100.3 | 100.18 | 1.230 | 0.251 |
| 110 | 100.1 | 100.9 | 99.1 | 100.2 | 100.7 | 100.4 | 100.23 | 1.277 | 0.261 |
| 120 | 100.1 | 101.0 | 99.1 | 100.3 | 100.7 | 100.5 | 100.29 | 1.320 | 0.269 |
| 130 | 100.2 | 101.1 | 99.2 | 100.3 | 100.9 | 100.6 | 100.36 | 1.335 | 0.272 |
| 140 | 100.2 | 101.1 | 99.2 | 100.4 | 100.9 | 100.6 | 100.41 | 1.378 | 0.281 |
| 150 | 100.2 | 101.2 | 99.1 | 100.5 | 101.0 | 100.6 | 100.44 | 1.448 | 0.296 |
| 160 | 100.3 | 101.3 | 99.1 | 100.5 | 101.0 | 100.6 | 100.48 | 1.496 | 0.305 |
| 170 | 100.3 | 101.3 | 99.2 | 100.6 | 101.1 | 100.6 | 100.53 | 1.502 | 0.307 |
| 180 | 100.4 | 101.4 | 99.6 | 100.9 | 101.0 | 100.5 | 100.62 | 1.265 | 0.258 |
| 190 | 100.4 | 101.4 | 99.5 | 100.9 | 100.9 | 100.4 | 100.60 | 1.310 | 0.267 |
| 200 | 100.5 | 101.6 | 99.4 | 100.9 | 100.9 | 100.3 | 100.59 | 1.489 | 0.304 |
| 210 | 100.6 | 101.7 | 99.3 | 100.9 | 100.9 | 100.1 | 100.58 | 1.603 | 0.327 |
| 220 | | 101.8 | 99.3 | 100.8 | 101.0 | 100.1 | 100.60 | 1.821 | 0.407 |
| 230 | | | 99.4 | 100.6 | 101.1 | 100.0 | 100.27 | 1.528 | 0.382 |
| 240 | | | 99.4 | 100.7 | 101.2 | 100.0 | 100.31 | 1.590 | 0.398 |
| 250 | | | 99.3 | 100.9 | 101.2 | 100.7 | 100.53 | 1.717 | 0.429 |
| 260 | | | 99.3 | 101.0 | 101.3 | 99.9 | 100.37 | 1.821 | 0.455 |
| 270 | | | 99.3 | 100.9 | 101.4 | | 100.54 | 2.266 | 0.654 |
| 280 | | | 99.2 | 100.9 | 101.5 | | 100.53 | 2.349 | 0.678 |
| 290 | | | 99.5 | 101.1 | | | 100.31 | 2.342 | 0.828 |
| 300 | | | 99.4 | 101.0 | | | 100.18 | 2.266 | 0.801 |
| 310 | | | 99.3 | 100.9 | | | 100.10 | 2.215 | 0.783 |
| 320 | | | 99.3 | 100.7 | | | 100.03 | 1.960 | 0.693 |
| 330 | | | 99.4 | 100.7 | | | 100.05 | 1.858 | 0.657 |
| 340 | | | | 100.7 | | | 100.69 | | |
| 350 | | | | 100.7 | | | 100.72 | | |
| 360 | | | | 100.8 | | | 100.81 | | |
| 370 | | | | 100.9 | | | 100.85 | | |
| 380 | | | | 100.9 | | | 100.90 | | |
| 390 | | | | 101.0 | | | 101.01 | | |

Appendix F.

Heart rate data.

| SOAR-specific MOPP4 with MCC | | | | | | | |
|------------------------------|---------|---------|---------|---------|-------|------|------|
| Test date -> | 6/17/98 | 6/17/98 | 6/18/97 | 6/18/98 | | | |
| Ensemble -> | SC | SC | SC | SC | | | |
| TS# --> | 1 | 2 | 3 | 4 | Mean | 2*SD | 2*SE |
| 0 | 78 | 85 | 80 | 74 | 79.3 | 9.1 | 4.6 |
| 10 | 92 | 115 | 97 | 130 | 108.5 | 34.8 | 17.4 |
| 20 | 114 | 116 | 97 | 141 | 117.0 | 36.3 | 18.1 |
| 30 | | | | | | | |
| 40 | 80 | 93 | | | 86.8 | 18.2 | 12.9 |
| 50 | 77 | 91 | 60 | 84 | 77.9 | 26.5 | 13.3 |
| 60 | 75 | 83 | 60 | 76 | 73.5 | 19.3 | 9.7 |
| 70 | 76 | 90 | 62 | 74 | 75.5 | 23.1 | 11.6 |
| 80 | 78 | 84 | 62 | 81 | 76.1 | 19.6 | 9.8 |
| 90 | 77 | 81 | 62 | 72 | 73.1 | 16.7 | 8.3 |
| 100 | 77 | 89 | 68 | 70 | 76.0 | 18.8 | 9.4 |
| 110 | 92 | 104 | 63 | 71 | 82.3 | 37.1 | 18.6 |
| 120 | 74 | 97 | 58 | 70 | 74.7 | 32.3 | 16.1 |
| 130 | 77 | 98 | 60 | 73 | 77.2 | 31.7 | 15.9 |
| 140 | 76 | 100 | 63 | 69 | 77.0 | 32.0 | 16.0 |
| 150 | 79 | 101 | 55 | 82 | 79.1 | 37.4 | 18.7 |
| 160 | 75 | 83 | 58 | 72 | 72.0 | 20.7 | 10.4 |
| 170 | 70 | 79 | 55 | 62 | 66.5 | 20.5 | 10.2 |
| 180 | 73 | 86 | 54 | 69 | 70.5 | 26.6 | 13.3 |
| 190 | 75 | 83 | 56 | 69 | 70.7 | 22.5 | 11.2 |
| 200 | 73 | 99 | 61 | 70 | 75.7 | 32.7 | 16.3 |
| 210 | 71 | 88 | 54 | 69 | 70.7 | 28.2 | 14.1 |
| 220 | 73 | 91 | 57 | 74 | 73.7 | 27.4 | 13.7 |
| 230 | 73 | 81 | 66 | 73 | 73.3 | 12.5 | 6.3 |
| 240 | 64 | 88 | 56 | 71 | 69.8 | 27.1 | 13.6 |
| 250 | 72 | 93 | 59 | 67 | 72.8 | 29.0 | 14.5 |
| 260 | 72 | 80 | 65 | 69 | 71.4 | 12.5 | 6.3 |
| 270 | 72 | 95 | 52 | 63 | 70.5 | 36.5 | 18.2 |
| 280 | 76 | 87 | 56 | 71 | 72.7 | 26.0 | 13.0 |
| 290 | 71 | 73 | 56 | 63 | 65.8 | 15.7 | 7.9 |
| 300 | 71 | 82 | 52 | 71 | 69.0 | 24.9 | 12.5 |
| 310 | 72 | 88 | 55 | 65 | 70.0 | 28.0 | 14.0 |
| 320 | 73 | 76 | 52 | 63 | 66.2 | 22.1 | 11.0 |
| 330 | 70 | 85 | 55 | 65 | 68.8 | 25.2 | 12.6 |
| 340 | 71 | 86 | 59 | 63 | 69.8 | 23.7 | 11.8 |
| 350 | 72 | 89 | 63 | 65 | 72.1 | 23.6 | 11.8 |
| 360 | 65 | 96 | 53 | 62 | 68.9 | 37.1 | 18.5 |
| 370 | | | | | | | |

| SOAR-specific MOPP4 without MCC | | | | | | | |
|---------------------------------|---------|---------|---------|---------|-------|------|------|
| Test date -> | 6/16/98 | 6/16/98 | 6/21/98 | 6/21/98 | | | |
| Ensemble -> | SX | SX | SX | SX | SX | SX | SX |
| TS# --> | 3 | 4 | 1 | 2 | Mean | 2*SD | 2*SE |
| 0 | 83 | 64 | 67 | 80 | 73.5 | 18.8 | 9.4 |
| 10 | 121 | 72 | 104 | 118 | 103.8 | 44.9 | 22.4 |
| 20 | | 128 | 111 | 114 | 117.7 | 18.1 | 10.5 |
| 30 | | | | | | | |
| 40 | 85.7 | 122.9 | 104 | 97 | 102.4 | 31.2 | 15.6 |
| 50 | 85 | 130 | 98 | 97 | 102.5 | 38.5 | 19.3 |
| 60 | 84.7 | 116.4 | 72 | 98 | 92.8 | 38.0 | 19.0 |
| 70 | 94 | 119.9 | 71 | 93 | 94.5 | 40.0 | 20.0 |
| 80 | 86.9 | 125.9 | 78 | 89 | 95.0 | 42.4 | 21.2 |
| 90 | 93.7 | 127.8 | 81 | 93 | 98.9 | 40.3 | 20.1 |
| 100 | 90.5 | 128.5 | 76 | 96 | 97.8 | 44.3 | 22.2 |
| 110 | 85.7 | 130 | 70 | 99 | 96.2 | 51.0 | 25.5 |
| 120 | 98.2 | 129 | 79 | 98 | 101.1 | 41.4 | 20.7 |
| 130 | 91.9 | 131 | 78 | 107 | 102.0 | 45.4 | 22.7 |
| 140 | 87.9 | 133 | 74 | 102 | 99.2 | 50.5 | 25.3 |
| 150 | 93.7 | 135 | 82 | 109 | 104.9 | 45.8 | 22.9 |
| 160 | 91 | 126 | 72 | 110 | 99.8 | 46.8 | 23.4 |
| 170 | 99.3 | 134 | 73 | 104 | 102.6 | 50.0 | 25.0 |
| 180 | 95.2 | 129 | 79 | 100 | 100.8 | 41.7 | 20.8 |
| 190 | 90.3 | 136 | 79 | 103 | 102.1 | 49.3 | 24.7 |
| 200 | 103.9 | 143 | 78 | 93 | 104.5 | 55.6 | 27.8 |
| 210 | 92.2 | 145 | 83 | 91 | 102.8 | 56.9 | 28.4 |
| 220 | | 147 | 75 | 102 | 108.0 | 72.7 | 42.0 |
| 230 | | | 70 | 101 | 85.5 | 43.8 | 31.0 |
| 240 | | | 86 | 104 | 95.0 | 25.5 | 18.0 |
| 250 | | | 83 | 112 | 97.5 | 41.0 | 29.0 |
| 260 | | | 77 | 104 | 90.5 | 38.2 | 27.0 |
| 270 | | | 76 | 110 | 93.0 | 48.1 | 34.0 |
| 280 | | | 70 | 108 | 89.0 | 53.7 | 38.0 |
| 290 | | | 67 | 105 | 86.0 | 53.7 | 38.0 |
| 300 | | | 69 | 104 | 86.5 | 49.5 | 35.0 |
| 310 | | | 73 | 105 | 89.0 | 45.3 | 32.0 |
| 320 | | | 75 | 109 | 92.0 | 48.1 | 34.0 |
| 330 | | | 75 | 108 | 91.5 | 46.7 | 33.0 |
| 340 | | | | 109 | 109.0 | | |
| 350 | | | | 111 | 111.0 | | |
| 360 | | | | 115 | 115.0 | | |
| 370 | | | | 113 | 113.0 | | |
| 380 | | | | 114 | 114.0 | | |
| 390 | | | | 118 | 118 | | |

| AW MOPP4 Concept1 without MCC | | | | | |
|-------------------------------|---------|---------|-------|------|------|
| Test date -> | 6/19/98 | 6/20/98 | | | |
| | AX | AX | AX | AX | AX |
| TS# --> | 2 | 3 | Mean | 2*SD | 2*SE |
| 0 | 101 | 83 | 92.0 | 25.5 | 18.0 |
| 10 | 120 | 123 | 121.5 | 4.2 | 3.0 |
| 20 | 132 | | 132.0 | | |
| 30 | | | | | |
| 40 | 122 | 85 | 103.5 | 52.3 | 37.0 |
| 50 | 125 | 83 | 104.0 | 59.4 | 42.0 |
| 60 | 116 | 73 | 94.5 | 60.8 | 43.0 |
| 70 | 113 | 84 | 98.5 | 41.0 | 29.0 |
| 80 | 116 | 80 | 98.0 | 50.9 | 36.0 |
| 90 | 119 | 85 | 102.0 | 48.1 | 34.0 |
| 100 | 120 | 82 | 101.0 | 53.7 | 38.0 |
| 110 | 122 | 101 | 111.5 | 29.7 | 21.0 |
| 120 | 125 | 88 | 106.5 | 52.3 | 37.0 |
| 130 | 132 | 93 | 112.5 | 55.2 | 39.0 |
| 140 | 134 | 86 | 110.0 | 67.9 | 48.0 |
| 150 | 127 | 85 | 106.0 | 59.4 | 42.0 |
| 160 | 133 | 82 | 107.5 | 72.1 | 51.0 |
| 170 | 134 | 83 | 108.5 | 72.1 | 51.0 |
| 180 | 130 | 80 | 105.0 | 70.7 | 50.0 |
| 190 | 132 | 81 | 106.5 | 72.1 | 51.0 |
| 200 | 131 | 86 | 108.5 | 63.6 | 45.0 |
| 210 | 123 | 74 | 98.5 | 69.3 | 49.0 |
| 220 | 128 | 76 | 102.0 | 73.5 | 52.0 |
| 230 | 125 | 80 | 102.5 | 63.6 | 45.0 |
| 240 | 133 | 78 | 105.5 | 77.8 | 55.0 |
| 250 | 129 | 75 | 102.0 | 76.4 | 54.0 |
| 260 | 134 | 88 | 111.0 | 65.1 | 46.0 |
| 270 | 131 | | 131.0 | | |
| 280 | 130 | | 130.0 | | |
| 290 | | | | | |
| 300 | | | | | |
| 310 | | | | | |
| 320 | | | | | |
| 330 | | | | | |
| 340 | | | | | |
| 350 | | | | | |
| 360 | | | | | |
| 370 | | | | | |
| 380 | | | | | |
| 390 | | | | | |

| AW MOPP4 Concept3 with MCC | | | | | |
|----------------------------|---------|---------|-------|------|------|
| Test date -> | 6/19/98 | 6/20/98 | | | |
| Ensemble -> | AC | AC | AC | AC | AC |
| TS# --> | 1 | 4 | Mean | 2*SD | 2*SE |
| 0 | 79 | 83 | 81.0 | 5.7 | 4.0 |
| 10 | 91 | 83 | 87.0 | 11.3 | 8.0 |
| 20 | 101 | | 101.0 | | |
| 30 | | | | | |
| 40 | 69 | 81 | 75.0 | 17.0 | 12.0 |
| 50 | 71 | 75 | 73.0 | 5.7 | 4.0 |
| 60 | 73 | 72 | 72.5 | 1.4 | 1.0 |
| 70 | 73 | 69 | 71.0 | 5.7 | 4.0 |
| 80 | 70 | 76 | 73.0 | 8.5 | 6.0 |
| 90 | 77 | 69 | 73.0 | 11.3 | 8.0 |
| 100 | 73 | 68 | 70.5 | 7.1 | 5.0 |
| 110 | 70 | 83 | 76.5 | 18.4 | 13.0 |
| 120 | 71 | 77 | 74.0 | 8.5 | 6.0 |
| 130 | 69 | 66 | 67.5 | 4.2 | 3.0 |
| 140 | 66 | 63 | 64.5 | 4.2 | 3.0 |
| 150 | 63 | 69 | 66.0 | 8.5 | 6.0 |
| 160 | 69 | 64 | 66.5 | 7.1 | 5.0 |
| 170 | 64 | 64 | 64.0 | 0.0 | 0.0 |
| 180 | 73 | 61 | 67.0 | 17.0 | 12.0 |
| 190 | 62 | 66 | 64.0 | 5.7 | 4.0 |
| 200 | 64 | 62 | 63.0 | 2.8 | 2.0 |
| 210 | 67 | 72 | 69.5 | 7.1 | 5.0 |
| 220 | 65 | 60 | 62.5 | 7.1 | 5.0 |
| 230 | 74 | 65 | 69.5 | 12.7 | 9.0 |
| 240 | 76 | 67 | 71.5 | 12.7 | 9.0 |
| 250 | 68 | 68 | 68.0 | 0.0 | 0.0 |
| 260 | 75 | 63 | 69.0 | 17.0 | 12.0 |
| 270 | 68 | | 68.0 | | |
| 280 | 68 | 78 | 73.0 | 14.1 | 10.0 |
| 290 | 67 | 66 | 66.5 | 1.4 | 1.0 |
| 300 | 74 | 61 | 67.5 | 18.4 | 13.0 |
| 310 | 70 | 73 | 71.5 | 4.2 | 3.0 |
| 320 | 65 | 63 | 64.0 | 2.8 | 2.0 |
| 330 | 69 | 65 | 67.0 | 5.7 | 4.0 |
| 340 | 72 | 61 | 66.5 | 15.6 | 11.0 |
| 350 | 69 | 62 | 65.5 | 9.9 | 7.0 |
| 360 | 62 | 71 | 66.5 | 12.7 | 9.0 |
| 370 | 69 | 66 | 67.5 | 4.2 | 3.0 |
| 380 | 65 | 64 | 64.5 | 1.4 | 1.0 |
| 390 | | 64 | 64.0 | | |
| | | 62 | 62.0 | | |

| Ensemble TS # | With Microclimate Cooling | | | | | | *C Mean | *C 2*SD | *C 2*SE |
|------------------|---------------------------|---------|---------|---------|---------|---------|------------|------------|------------|
| | SC 1 | SC 2 | SC 3 | SC 4 | AC 1 | AC 4 | | | |
| 0 | 78 | 85 | 80 | 74 | 79 | 83 | 79.8 | 7.7 | 3.2 |
| 10 | 92 | 115 | 97 | 130 | 91 | 83 | 101.3 | 35.3 | 14.4 |
| 20 | 114 | 116 | 97 | 141 | 101 | | 113.8 | 34.5 | 15.4 |
| 30 | | | | | | | | | |
| 40 | 80.3 | 93.2 | | | 69 | 81 | 80.9 | 19.8 | 9.9 |
| 50 | 76.5 | 90.9 | 60 | 84 | 71 | 75 | 76.2 | 21.3 | 8.7 |
| 60 | 74.8 | 83 | 60 | 76 | 73 | 72 | 73.1 | 15.0 | 6.1 |
| 70 | 75.9 | 90.2 | 62 | 74 | 73 | 69 | 74.0 | 18.7 | 7.6 |
| 80 | 77.5 | 84 | 62 | 81 | 70 | 76 | 75.1 | 16.0 | 6.5 |
| 90 | 77.2 | 81.3 | 62 | 72 | 77 | 69 | 73.1 | 13.9 | 5.7 |
| 100 | 77.2 | 88.8 | 68 | 70 | 73 | 68 | 74.2 | 16.0 | 6.5 |
| 110 | 91.5 | 103.5 | 63 | 71 | 70 | 83 | 80.3 | 30.5 | 12.5 |
| 120 | 74.1 | 96.6 | 58 | 70 | 71 | 77 | 74.5 | 25.3 | 10.3 |
| 130 | 77.4 | 98.2 | 60 | 73 | 69 | 66 | 73.9 | 26.6 | 10.9 |
| 140 | 76.3 | 99.5 | 63 | 69 | 66 | 63 | 72.8 | 28.0 | 11.4 |
| 150 | 79 | 100.5 | 55 | 82 | 63 | 69 | 74.8 | 32.2 | 13.1 |
| 160 | 75.2 | 82.8 | 58 | 72 | 69 | 64 | 70.2 | 17.3 | 7.1 |
| 170 | 70.2 | 78.7 | 55 | 62 | 64 | 64 | 65.7 | 16.1 | 6.6 |
| 180 | 72.5 | 86.4 | 54 | 69 | 73 | 61 | 69.3 | 22.3 | 9.1 |
| 190 | 75.2 | 82.5 | 56 | 69 | 62 | 66 | 68.5 | 18.9 | 7.7 |
| 200 | 72.8 | 99 | 61 | 70 | 64 | 62 | 71.5 | 28.5 | 11.6 |
| 210 | 71.4 | 88.4 | 54 | 69 | 67 | 72 | 70.3 | 22.1 | 9.0 |
| 220 | 73.2 | 90.5 | 57 | 74 | 65 | 60 | 70.0 | 24.3 | 9.9 |
| 230 | 72.8 | 81.3 | 66 | 73 | 74 | 65 | 72.0 | 11.9 | 4.9 |
| 240 | 64.2 | 87.9 | 56 | 71 | 76 | 67 | 70.4 | 21.8 | 8.9 |
| 250 | 72.3 | 93 | 59 | 67 | 68 | 68 | 71.2 | 23.0 | 9.4 |
| 260 | 71.9 | 79.8 | 65 | 69 | 75 | 63 | 70.6 | 12.6 | 5.1 |
| 270 | 72.2 | 94.9 | 52 | 63 | 68 | | 70.0 | 31.7 | 14.2 |
| 280 | 76.4 | 87.2 | 56 | 71 | 68 | 78 | 72.8 | 21.1 | 8.6 |
| 290 | 71.2 | 73 | 56 | 63 | 67 | 66 | 66.0 | 12.2 | 5.0 |
| 300 | 71 | 82 | 52 | 71 | 74 | 61 | 68.5 | 21.0 | 8.6 |
| 310 | 71.7 | 88.3 | 55 | 65 | 70 | 73 | 70.5 | 21.8 | 8.9 |
| 320 | 73.2 | 76.4 | 52 | 63 | 65 | 63 | 65.4 | 17.3 | 7.1 |
| 330 | 69.9 | 85.2 | 55 | 65 | 69 | 65 | 68.2 | 19.7 | 8.1 |
| 340 | 71.3 | 85.8 | 59 | 63 | 72 | 61 | 68.7 | 19.9 | 8.1 |
| 350 | 71.5 | 89 | 63 | 65 | 69 | 62 | 69.9 | 20.0 | 8.2 |
| 360 | 64.8 | 95.6 | 53 | 62 | 62 | 71 | 68.1 | 29.4 | 12.0 |
| 370 | | | | | 69 | 66 | 67.5 | 4.2 | 3.0 |
| 380 | | | | | 65 | 64 | 64.5 | 1.4 | 1.0 |
| 390 | | | | | | 64 | 64.0 | | |
| | | | | | | 62 | 62.0 | | |

| Ensemble TS # | Without Microclimate Cooling | | | | | | *X Mean | *X 2*SD | *X 2*SE |
|------------------|------------------------------|---------|---------|---------|---------|---------|------------|------------|------------|
| | SX 3 | SX 4 | SX 1 | SX 2 | AX 2 | AX 3 | | | |
| 0 | 83 | 64 | 67 | 80 | 101 | 83 | 79.7 | 26.6 | 10.9 |
| 10 | 121 | 72 | 104 | 118 | 120 | 123 | 109.7 | 39.3 | 16.1 |
| 20 | | 128 | 111 | 114 | 132 | | 121.3 | 20.6 | 10.3 |
| 30 | | | | | | | | | |
| 40 | 85.7 | 122.9 | 104 | 97 | 122 | 85 | 102.8 | 33.7 | 13.7 |
| 50 | 85 | 130 | 98 | 97 | 125 | 83 | 103.0 | 40.0 | 16.3 |
| 60 | 84.7 | 116.4 | 72 | 98 | 116 | 73 | 93.4 | 40.1 | 16.4 |
| 70 | 94 | 119.9 | 71 | 93 | 113 | 84 | 95.8 | 36.2 | 14.8 |
| 80 | 86.9 | 125.9 | 78 | 89 | 116 | 80 | 96.0 | 40.1 | 16.4 |
| 90 | 93.7 | 127.8 | 81 | 93 | 119 | 85 | 99.9 | 38.0 | 15.5 |
| 100 | 90.5 | 128.5 | 76 | 96 | 120 | 82 | 98.8 | 42.1 | 17.2 |
| 110 | 85.7 | 130 | 70 | 99 | 122 | 101 | 101.3 | 44.5 | 18.2 |
| 120 | 98.2 | 129 | 79 | 98 | 125 | 88 | 102.9 | 40.1 | 16.4 |
| 130 | 91.9 | 131 | 78 | 107 | 132 | 93 | 105.5 | 44.3 | 18.1 |
| 140 | 87.9 | 133 | 74 | 102 | 134 | 86 | 102.8 | 50.8 | 20.7 |
| 150 | 93.7 | 135 | 82 | 109 | 127 | 85 | 105.3 | 44.3 | 18.1 |
| 160 | 91 | 126 | 72 | 110 | 133 | 82 | 102.3 | 49.2 | 20.1 |
| 170 | 99.3 | 134 | 73 | 104 | 134 | 83 | 104.6 | 50.8 | 20.7 |
| 180 | 95.2 | 129 | 79 | 100 | 130 | 80 | 102.2 | 45.4 | 18.5 |
| 190 | 90.3 | 136 | 79 | 103 | 132 | 81 | 103.6 | 50.2 | 20.5 |
| 200 | 103.9 | 143 | 78 | 93 | 131 | 86 | 105.8 | 51.8 | 21.1 |
| 210 | 92.2 | 145 | 83 | 91 | 123 | 74 | 101.4 | 54.0 | 22.1 |
| 220 | | 147 | 75 | 102 | 128 | 76 | 105.6 | 63.6 | 28.4 |
| 230 | | | 70 | 101 | 125 | 80 | 94.0 | 48.7 | 24.4 |
| 240 | | | 86 | 104 | 133 | 78 | 100.3 | 48.8 | 24.4 |
| 250 | | | 83 | 112 | 129 | 75 | 99.8 | 50.3 | 25.2 |
| 260 | | | 77 | 104 | 134 | 88 | 100.8 | 49.6 | 24.8 |
| 270 | | | 76 | 110 | 131 | | 105.7 | 55.5 | 32.0 |
| 280 | | | 70 | 108 | 130 | | 102.7 | 60.7 | 35.0 |
| 290 | | | 67 | 105 | | | 86.0 | 53.7 | 38.0 |
| 300 | | | 69 | 104 | | | 86.5 | 49.5 | 35.0 |
| 310 | | | 73 | 105 | | | 89.0 | 45.3 | 32.0 |
| 320 | | | 75 | 109 | | | 92.0 | 48.1 | 34.0 |
| 330 | | | 75 | 108 | | | 91.5 | 46.7 | 33.0 |
| 340 | | | | 109 | | | 109.0 | | |
| 350 | | | | 111 | | | 111.0 | | |
| 360 | | | | 115 | | | 115.0 | | |
| 370 | | | | 113 | | | 113.0 | | |
| 380 | | | | 114 | | | 114.0 | | |
| 390 | | | | 118 | | | 118.0 | | |

Appendix G.

Weight and fluid balance data.

| Weight and Fluid Balance | | | | | | | |
|----------------------------------|--|-------|-------|-------|--------|---------|---------|
| SOAR-specific w/ cooling (SC) | | TS 1 | TS 2 | TS 3 | TS4 | AVG | SE |
| SC | TIME IN UNIFORM (hours) | 6.78 | 6.78 | 6.82 | 6.82 | 6.80 | 0.010 |
| SC | URINE OUTPUT RATE (ml/hr) | 287.2 | 447.0 | 166.7 | 236.5 | 284.32 | 59.582 |
| SC | URINE OUTPUT (gms) | 1948 | 3032 | 1136 | 1612 | 1932.00 | 402.727 |
| SC | FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gm) | 347 | 410 | 90 | 257 | 276.13 | 69.584 |
| SC | FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms) | 2356 | 2782 | 612 | 1754 | 1876.00 | 471.152 |
| SC | SWEAT LOSS RATE (ml/hr) | 212.0 | 280.1 | 137.6 | 167.5 | 199.31 | 30.984 |
| SC | TOT SWEAT LOSS (gms) | 1438 | 1900 | 938 | 1142 | 1354.50 | 208.800 |
| SC | % DEHYDRATION | 1.19 | 2.47 | 1.67 | 1.03 | 1.59 | 0.324 |
| SC | SWEAT RETAINED RATE (ml/hr) | 75.5 | 122.7 | 36.4 | 46.7 | 70.29 | 19.316 |
| SC | SWEAT RETAINED (gms) | 512 | 832 | 248 | 318 | 477.50 | 130.694 |
| SC | SWEAT EVAPORATION RATE (ml/hr) | 136.5 | 157.4 | 101.2 | 120.9 | 129.01 | 11.913 |
| SC | SWEAT EVAPORATED (gms) | 926 | 1068 | 690 | 824 | 877.00 | 79.927 |
| SC | % SWEAT EVAPORATED | 64 | 56 | 74 | 72 | 66.58 | 4.001 |
| SC | % SWEAT RETAINED | 36 | 44 | 26 | 28 | 33.42 | 4.001 |
| | | | | | | | |
| SOAR-specific w/out cooling (SX) | | TS 1 | TS 2 | TS 3 | TS4 | AVG | SE |
| SX | TIME IN UNIFORM (hours) | 6.72 | 6.72 | 3.83 | 3.92 | 5.30 | 0.820 |
| SX | URINE OUTPUT RATE (ml/hr) | 254.0 | 371.9 | 58.4 | 33.2 | 179.38 | 80.950 |
| SX | URINE OUTPUT (gms) | 1706 | 2498 | 224 | 130 | 1139.50 | 579.056 |
| SX | FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gm) | 737 | 821 | 385 | 729 | 667.78 | 96.670 |
| SX | FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms) | 4952 | 5512 | 1474 | 2854 | 3698.00 | 936.377 |
| SX | SWEAT LOSS RATE (ml/hr) | 602.1 | 417.8 | 721.0 | 1271.0 | 752.97 | 183.594 |
| SX | TOT SWEAT LOSS (gms) | 4044 | 2806 | 2764 | 4978 | 3648.00 | 533.552 |
| SX | % DEHYDRATION | 0.91 | -0.24 | 1.73 | 2.30 | 1.18 | 0.551 |
| SX | SWEAT RETAINED RATE (ml/hr) | 306.1 | 115.5 | 380.9 | 608.7 | 352.80 | 101.955 |
| SX | SWEAT RETAINED (gms) | 2056 | 776 | 1460 | 2384 | 1669.00 | 353.804 |
| SX | SWEAT EVAPORATION RATE (ml/hr) | 296.0 | 302.2 | 340.2 | 662.3 | 400.17 | 87.919 |
| SX | SWEAT EVAPORATED (gms) | 1988 | 2030 | 1304 | 2594 | 1979.00 | 264.028 |
| SX | % SWEAT EVAPORATED | 49 | 72 | 47 | 52 | 55.20 | 5.805 |
| SX | % SWEAT RETAINED | 51 | 28 | 53 | 48 | 44.80 | 5.805 |

| Weight and Fluid Balance | | | | | | |
|--------------------------------------|---|-------|-------|-------|---------|---------|
| Air Warrior Concept 3 w/MCC (AC) | | TS 1 | | TS 4 | AVG | SE |
| AC | TIME IN UNIFORM (hours) | 6.92 | | 6.88 | 6.90 | 0.017 |
| AC | URINE OUTPUT RATE (ml/hr) | 391.8 | | 262.7 | 327.24 | 64.572 |
| AC | URINE OUTPUT (gms) | 2710 | | 1808 | 2259.00 | 451.000 |
| AC | FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gm) | 377 | | 149 | 262.91 | 114.148 |
| AC | FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms) | 2608 | | 1024 | 1816.00 | 792.000 |
| AC | SWEAT LOSS RATE (ml/hr) | 221.8 | | 183.9 | 202.85 | 18.930 |
| AC | TOT SWEAT LOSS (gms) | 1534 | | 1268 | 1400.00 | 134.000 |
| AC | % DEHYDRATION | 1.88 | | 2.06 | 1.97 | 0.094 |
| AC | SWEAT RETAINED RATE (ml/hr) | 100.8 | | 72.9 | 86.78 | 13.848 |
| AC | SWEAT RETAINED (gms) | 696 | | 502 | 599.00 | 97.000 |
| AC | SWEAT EVAPORATION RATE (ml/hr) | 121.2 | | 111.0 | 116.07 | 5.082 |
| AC | SWEAT EVAPORATED (gms) | 838 | | 764 | 801.00 | 26.163 |
| AC | % SWEAT EVAPORATED | 55 | | 60 | 57.49 | 2.860 |
| AC | % SWEAT RETAINED | 45 | | 40 | 42.51 | 2.860 |
| Air Warrior Concept 1 w/out MCC (AX) | | TS 2 | TS 3 | | AVG | SE |
| AX | TIME IN UNIFORM (hours) | 5.00 | 4.55 | | 4.78 | 0.159 |
| AX | URINE OUTPUT RATE (ml/hr) | 350.8 | 37.4 | | 194.08 | 110.817 |
| AX | URINE OUTPUT (gms) | 1754 | 170 | | 962.00 | 560.029 |
| AX | FLUID INTAKE PER HOUR BETWEEN DRESSED WEIGHTS (gms) | 350 | 547 | | 448.43 | 69.881 |
| AX | FLUID INTAKE BETWEEN DRESSED WEIGHTS (gms) | 1748 | 2490 | | 2119.00 | 262.337 |
| AX | SWEAT LOSS RATE (ml/hr) | 558.4 | 971.4 | | 763.91 | 146.735 |
| AX | TOT SWEAT LOSS (gms) | 2782 | 4420 | | 3601.00 | 579.120 |
| AX | % DEHYDRATION | 3.23 | 2.40 | | 2.82 | 0.295 |
| AX | SWEAT RETAINED RATE (ml/hr) | 244.0 | 611.0 | | 427.49 | 129.750 |
| AX | SWEAT RETAINED (gms) | 1220 | 2780 | | 2000.00 | 551.543 |
| AX | SWEAT EVAPORATION RATE (ml/hr) | 312.4 | 360.4 | | 336.42 | 16.985 |
| AX | SWEAT EVAPORATED (gms) | 1562 | 1640 | | 1601.00 | 27.577 |
| AX | % SWEAT EVAPORATED | 56 | 37 | | 46.63 | 9.521 |
| AX | % SWEAT RETAINED | 44 | 63 | | 53.37 | 9.521 |

Appendix H.

Manufacturers and product information.

Digital Equipment Corporation
110 Spit Brook Road
Nashu, NH 03062-2698

VAX 11/780 Computer

Microsoft Corporation
P.O. Box 72368
Roselle, Illinois 66172-9900

Microsoft Office Professional

SPSS, Inc.
444 North Michigan Avenue
Chicago, Illinois 60611

SPSS statistical software

Statsoft
2325 East 13th Street
Tulsa, Oklahoma 74104

Statistica software

Vermont Medical, Inc.
Industrial Park
Bellows Falls, Vermont 05101-3122

ECG pads

Yellow Springs Instrument Company
P.O. Box 279
Yellow Springs, Ohio 45387

Rectal and skin thermistors